

ORGANIC MANURES

A C GAUR • S NEELAKANTAN • K S DARGAN



INDIAN COUNCIL OF AGRICULTURAL RESEARCH
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MANURES**

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FOREWORD

THE IMPORTANCE of organic manures as a source of humus and plant nutrients to increase the fertility level of tropical soils has been well recognised. The organic matter content of cultivated soils of the tropics and sub-tropics is comparatively low due to high temperature and intense microbial activity. Therefore, soil humus has to be replenished through periodic additions of organic manures for maintaining soil productivity. With the rising costs of fossil fuels we are facing acute problems in the areas of energy and production of chemical fertilizers. Availability of chemical fertilizers to the farmer at reasonable cost is fast declining. There is, thus, a need for utilising organic manure/wastes for supplementing chemical fertilizers in the present context. The preparation of organic manures from rural and urban wastes would provide not only the plant nutrients and humic materials but also will result in hygienic disposal of the organic wastes which otherwise may cause pollution problems. Moreover, during recent years the concept of integrated nutrient supply involving organic and inorganic fertilizers has developed to meet the growing need for nutrient supplies for high-yielding varieties under conditions of intensive agriculture.

The literature on organic manures including the livestock manure, human excreta, crop wastes and industrial organic wastes and their efficient utilisation for better crop production was reviewed earlier by Garg *et al.* 1971. The present bulletin has brought out the recent research findings and their application under field conditions in the context of present energy and fertilizer shortage. The potential of the various organic manures has been assessed, their nature and different characteristics as well as the various methods of composting with minimum loss of plant nutrients have been detailed. Recent research trends such as rapid composting by inoculation of compost heap by cellulolytic cultures, enrichment of compost by application of rockphosphate, and inoculation with nitrogen-fixing and phosphate-solubilising micro-organisms and efficient methods of recycling of crop-wastes in relation to crop growth in different agriculture systems have been discussed. The bulletin has been revised and updated with the recent field data on organic manures and crop yields. A few new chapters such as recycling of organic materials as fertilizers, the scope of utilising various organic wastes for obtaining methane gas by anaerobic digestion and the manurial value of digested spent slurry on crop response have also been included. The authors have taken great pains in revising the bulletin and

ORGANIC MANURES

including new information on different organic manures. I hope that this bulletin will be of immense value to research workers and students interested in organic manures and to farmers who could choose the technology suitable for their farming systems depending on the availability of different types of organic wastes.

New Delhi
November 18, 1980

O. P. GAUTAM
Director-General
Indian Council of Agricultural Research

CONTENTS

Foreword	...	v
I. Introduction	...	1
II. Organic Manures, Their Nature and Characteristics	...	3
III. Livestock and Human Wastes — Characteristics and Manurial Value	...	11
IV. Available Potential of Organic Materials and Plant Nutrients	...	23
V. Fundamentals and Preparation, Processing and Preservation of Organic Manures	...	42
VI. Biogas Potential from Livestock Wastes and Human Excreta and Manurial Value of Digested Slurry and Sludge	...	72
VII. Recycling of Organic Materials as Fertilizers	...	79
VIII. Response of Crops to Organic Manures in Normal Soil	...	96
IX. Response of Crops to Organic Materials in Salt-affected Soils	...	144
X. Recommendations	..	149
XI. Average Chemical Composition of Different Manures	...	153
Bibliography	...	155

I. INTRODUCTION

MILLIONS of farmers in developing countries need adequate resources for augmenting the crop productivity. Proper soil management ensuring continued maintenance and building up of soil fertility is indispensable for greater productivity from agricultural land. There is no need to emphasise that organic manures influence favourably plant growth and yield directly as well as indirectly.

The indirect effects include augmentation of beneficial microbial population and their activities such as organic matter decomposition (Gaur *et al.*, 1971, 1973 ; Gaur and Pareek, 1974), biological nitrogen fixation (Gaur and Mathur, 1966 ; Bhardwaj and Gaur, 1970), solubilisation of insoluble phosphates (Gaur, 1972) and availability of plant nutrients. In addition to nitrogen, phosphorus and potassium, a fair amount of micronutrients such as manganese, zinc, copper and iron are simultaneously added to soil. Organic manures improve the soil structure (Gaur *et al.*, 1972), seed germination, waterholding capacity, drainage, base exchange capacity and check soil erosion. The direct effects relate to the uptake of humic substances or its decomposition products affecting favourably the growth and metabolism of plants (Gaur, 1971 ; Gaur and Bhardwaj, 1971 ; Khandelwal and Gaur, 1970 ; Mathur and Gaur, 1977). Humic substances have been reported to increase the efficiency of bio-and chemical-fertilizers. Researches at I.A.R.I. have also shown that organic materials check proliferation of plant parasitic soil nematodes (Gaur and Prasad, 1970 ; Prasad *et al.*, 1972).

The crops remove annually large quantities of plant nutrients from soil. Much of the plant nutrients thus removed can be restored through application of organic manures. Moreover, Indian soils are poor in organic matter and in major plant nutrients. The research work carried out in All-India Coordinated Project on "Decomposition of Organic Matter in Indian Soils" during 1967-71 showed that farmyard manure or compost was the best source for maintenance of soil organic matter at higher level. Therefore, regular application of organic manure is a sound practice for maintaining the soil fertility in tropical soils.

Due to energy crisis, prohibitive cost of chemical fertilizers and poor purchasing power of marginal and small farmers, it is imperative to develop strategy to use organic manures/wastes to its maximum potential with proper technology to meet the shortage of fertilizers and for improving soil fertility. The use of organic fertilizers has the advantage of converting unusual

ORGANIC MANURES

surplus/wastes into useful product for use in agriculture. In recent years, concept of integrated nutrient supply involving combined use of organic and chemical fertilizers has also been developed. The use of adequate doses of organic manures coupled with chemical fertilizers will ensure optimum growth conditions under intensive pattern of farming using high-yielding varieties. Besides NPK, organic manures are a potential source of micronutrients. The micronutrient content in organic manures/organic materials varies considerably depending upon the nature, source, and extent of decomposition. There may be considerable variation in the contents of the micronutrients even though the nature of manure is similar (Katyal, Randhawa and Roy, 1979). In long-term manurial experiments, continuous application of farmyard manure in maize-wheat rotation for 6 seasons almost doubled the build-up of available zinc (Mann *et al.*, 1977). The regulatory effect of organic manures on the availability of micronutrients through chelation process is caused by the humic substances and organic acid contained in it. The preparation of organic manure from rural and urban wastes will not only provide the valuable manure so badly required for our soils but will also result in hygienic disposal of solid and liquid wastes which otherwise cause pollution problems.

This bulletin deals only with such organic manures with which our farmers are already familiar. Commonly available organic manures include farmyard manure, composts of farm-wastes, crop residues, cattle-dung, night-soil and urine ; sweepings from cattle-shed, houses and streets; forest-litter; water hyacinth ; poultry, sheep and goat-droppings ; tankage, blood and meat-meal ; fish-meal ; guano ; shoddy ; oilcakes ; sewage; sullage; sludge and green manures. Large quantities of these manures, at present used either in an uneconomic manner or left completely unutilized, can be usefully exploited to add to the national wealth. An endeavour has been made to emphasize that the building up of the organic base of the soil is the most important measure to step up the yield. Accordingly the need for scientific conservation and planned utilization of all locally available organic wastes and manurial resources is very important and vital for soil health and crop productivity.

II. ORGANIC MANURES, THEIR NATURE AND CHARACTERISTICS

ORGANIC materials are valuable by-products of farming and allied industries, derived from plant and animal sources. Organic manures which are bulky in nature but supply the plant nutrients in small quantities are termed bulky organic manures, e.g. farmyard manure, rural and town compost, night-soil, green manure, etc. whereas those containing higher percentage of major plant nutrients like nitrogen, phosphorus and potash are concentrated organic manures, e.g. oil-cakes, blood and meat-meals, fish-meal, guano, shoddy and poultry manure, etc.

FARMYARD MANURE

This is the traditional organic manure and is most readily available to the farmers. In Western countries, it is the product of decomposition of the liquid and solid excreta of the livestock, stored in the farm along with varying amounts of straws or other litter used as bedding. Indian litter is rarely used as bedding because the straw is utilized as fodder. A portion of cattle-dung is used as fuel in rural homes. Cattle-urine is absorbed in the soil spread over the floor of the shed but no extra soil is used for effective absorption of this fraction.

On an average, well-rotted farmyard manure (FYM) contains 0.5 per cent N, 0.2 per cent P_2O_5 and 0.5 per cent K_2O . Based on this analysis, an average dressing of 25 tonnes per hectare of farmyard manure supplies 112 kg of N, 56 kg of P_2O_5 and 112 kg of K_2O . These quantities are not fully available to the crops in the year of application. Nitrogen is very slow-acting and less than 30 per cent of it is generally available to the first crop. About 60 to 70 per cent of the phosphate and about 75 per cent of the potash become available to the immediate crop. The rest of the plant nutrients become available to the subsequent crops. This phenomenon of availability of plant nutrients to the subsequent crop is known as residual effect.

Under the tropical climatic conditions of this country, the organic matter is quickly lost and fresh applications are necessary to obtain increased yields and maintain soil fertility.

High doses of farmyard manure can be applied under intensive irrigated cropping conditions, e.g. about 25 tonnes per hectare for sugarcane, vegetables, potatoes, rice, etc. 12.5 tonnes for irrigated or rain-fed crops where the rainfall is medium to heavy (about 125 cm) and from 5 to 7 tonnes in

ORGANIC MANURES

dry areas where the rainfall is low (about 50 cm). In dry-farming areas (rainfall below 50 cm), application of 2.5 tonnes of farmyard manure per hectare gives significant increase in crop yield.

The method of application of farmyard manure generally adopted in our country is defective. Most of the cultivators unload farmyard manure in small piles in the fields and leave it as such for a month or so before it is spread and subsequently ploughed in or disced in the field. Plant nutrients are lost considerably during the exposure of the manure to sun and rains. In summer, it results in rapid drying and considerable loss of nitrogen, whereas in the rainy season the available nitrogen and a good portion of soil humus are washed away. To derive maximum benefit, the farmyard manure immediately on being carted to fields should be spread and mixed into the soil. The manure can also be applied in furrows.

COMPOST

Compost manures are the decayed refuse like leaves, twigs, roots, stubble, *bhusa*, crop residue and hedge clippings, street refuse collected in towns and villages, water hyacinth, saw-dust and bagasse. The process of decomposition is hastened by adding nitrogenous material like cowdung, night-soil, urine or fertilizers. A large number of soil micro-organisms feed on these wastes and convert it into well-rotted manure. The final product is known as compost.

Farmyard manure and compost possess the same characteristics. The method of application of compost is the same as that of farmyard manure. The chemical composition of compost prepared from different sources is indicated below :

Sources of Manure	Nitrogen (N) %	Phosphorus (P ₂ O ₅) %	Potassium (K ₂ O) %
Farm litter	0.5	0.2	0.5
Water hyacinth	2.0	1.0	2.3
Town compost (street refuse, night-soil, urine, etc.)	1.5	1.0	1.5

SHEEP AND GOAT MANURE

The droppings of sheep and goats make a very good manure. Panning is, therefore, a common practice of ensuring the use of sheep and goat-droppings in the fields. Sheep and goat manure contains 3 per cent N, 1 per cent P₂O₅ and 2 per cent K₂O.

ORGANIC MANURES, THEIR NATURE AND CHARACTERISTICS

POULTRY MANURE

This is a rich organic manure, since liquid and solid excreta are excreted together resulting in no urine loss. Poultry manure ferments very quickly. If left exposed, it may lose up to 50 per cent of its nitrogen within 30 days.

Poultry manure can be applied to the soil directly as soon as possible. After application, it should be worked into the surface of the soil. If the droppings come from the cages or dropping pits, superphosphate may be added to these at the rate of 1 kg per day, per hundred birds. This improves the fertilizing quality and helps the control of flies and odour.

The average chemical composition of the poultry manure is as under:

Type	Moisture %	Nitrogen %	Phosphorus %	Potassium %
Fresh	75	1.47	1.15	0.48
Floor litter	24	3.03	2.63	1.40

OIL-CAKES

Oilseeds are generally rich in manurial ingredients. After oil extraction, the oil-cakes are rich in nitrogen and also contain phosphorus and potash.

Cultivators apply both edible and non-edible oil-cakes to the soil as manure. Edible oil-cakes are more profitable as cattle feeds. As such, non-edible cakes should be used as manures.

The percentage of nitrogen ranges from 2.5 in mahua to 7.9 in deoiled safflower cakes. The P_2O_5 contents in oil-cakes vary from 0.8 to 3 per cent and K_2O from 1.2 to 2.2 per cent.

Oil-cakes though insoluble in water are quick-acting organic manures, their nitrogen becoming quickly available to the plants in about a week or ten days after application. Mahua oil-cake, however, takes about two months to nitrify. The solvent-extracted oil-cakes are somewhat more quick-acting than the *ghani*-hydraulic or expeller-pressed oil-cakes. The quantity of organic matter that gets added in normal application of oil-cakes is too small to cause improvement in physical properties of soil.

Oil-cakes need to be well-powdered before application so that they can be spread evenly and are easily decomposed by micro-organisms. They can be applied a few days before sowing or as top-dressing. Mahua-cakes should, however, be applied quite in advance of sowing time. Oil-cakes are more effective in moist soil and in wet weather than in dry soil and in dry weather. In fresh condition, oil-cakes should not be put in contact with germinating seeds or young plants as they become permeated with fungi and molds in the soil.

ORGANIC MANURES

The use of oil-cakes on foodgrain crops like wheat and rice is not recommended now on economic grounds. Cakes, specially ground-nut and coconut, are extensively applied for top-dressing of sugar-cane crop. Farmers growing betel leaves also use oil-cakes.

MEAL GROUP OF MANURES

These are all quick-acting manures suitable for all types of soil and for all crops. In this group come blood-meal (generally used in grape cultivation), meat-meal, fish-meal, horn- and hoof-meal and bone-meal. Meat-meal and blood-meal are applied like oil-cakes whereas fish-meal should preferably be powdered. Horns and hooves of slaughtered or dead animals are converted into horn and hoof-meal by cooking in the bone-digester, and then drying and powdering them. Their average chemical composition is given below :

Type	Nitrogen %	Phosphorus %	Potassium %
Blood-meal	10-12	1.2	1
Meat-meal	10.5	2.5	0.5
Fish-meal	4-10	3.9	0.3-1.5
Horn and hoof-meal	13	—	—
Raw bone-meal	3-4	20-25	—
Steamed bone-meal	1-2	25-30	—

Bone-meal. Sterilized bone-meal is an important mineral supplement in livestock feed; yet it is used chiefly as phosphatic fertilizer. Small quantities of nitrogen are also applied to the soil through bone-meal. The availability of phosphorus from bone-meal depends on the particle size; the finer the particles, the greater the phosphorus availability. It is available to farmers in two forms : (a) raw bone-meal; and (b) steamed bone-meal.

Raw bone-meal consists of crushed bones. The percentage of phosphoric acid and nitrogen varies with the quality of bones and the age of the animals from which these are obtained. Normally, the bones of grown-up animals contain more of phosphoric acid and less nitrogen than those of the young ones. According to the standards laid down by Indian Standards Institution, the raw bone-meal must pass wholly through 2.3 mm I.S. sieve of which not more than 30 per cent shall be retained on 850 micron I.S. sieve.

Steamed bone-meal is obtained by treating the bones with steam under pressure and is generally preferred to raw bone-meal. Steaming increases the percentage of phosphoric acid and reduces the nitrogen content of the bone-meal. It also removes the fat from the bones which makes bone-meal

ORGANIC MANURES, THEIR NATURE AND CHARACTERISTICS

very porous and easy to grind. Steamed bone-meal also decomposes more rapidly in the soil than raw bone-meal. According to I.S.I. standards, not less than 90 per cent of the material should pass through 1.18 mm I.S. sieve. Other specifications laid down by I.S.I. for the chemical composition of raw and steamed bone-meal are as under :

	Raw bone-meal	Steamed bone-meal
1. Moisture percentage by weight (maximum)	8	7
2. Total phosphates percentage (as P_2O_5) by weight (minimum)	20	22
3. Available phosphates (as P_2O_5) soluble in 2% citric acid solution, percentage by weight (minimum)	8	16
4. Nitrogen percentage by weight (minimum)	3	—

Bone-meal is considered useful for all soils. Best results are, however, obtained on acidic soils and soils having good drainage. It is less effective on heavy clay and calcareous soils. It has particularly notable effect on soils which are well-supplied with organic matter. Paddy, wheat and other cereals respond very well to bone-meal particularly in acidic soils. Sugar-cane, vegetables, fruits, leguminous crops, pastures and grasses are all benefited by this manure.

Bone-meal is applied to the soil at sowing time or just before it. Its use as top-dressing is not recommended. It is preferably drilled in the soil. A dose of 112–224 kg per hectare is sufficient for most cereal crops. For vegetables and fruits, about 500 to 600 kg of bone-meal per hectare is applied.

SEWAGE, SLUDGE AND SULLAGE

In big cities provided with underground sewage and flush system a good deal of night-soil and urine dissolved in water used for flushing is available. This is known as sewage. In smaller towns, the bathroom and kitchen washings, urine, etc. are carried in open gutters. This is known as sullage. Both these are rich in nitrogen and other plant nutrients.

Sewage has two components : (a) Solid portion or sludge; and (b) liquid portion or sewage water. The sewage should first be settled to remove the major portion of the suspended solids and effluent, which is 99 per cent constituent of sewage. The sludge should be separately collected and dried and used as manure on lands not treated with sewage. The sludges may be classified as (a) settled sludge, produced by plain sedimentation, (b) digested sludge, resulting from anaerobic decomposition of sedimented sludge, (c)

ORGANIC MANURES

activated sludge, produced by a special rapid aerobic treatment of sewage that results in coagulation and settling of suspended material, (d) digested activated sludge, and (e) chemically precipitated sludge.

Characteristics. The characteristics of sewage show considerable variations obtained from one source to another. The quality of sewage also changes as a result of discharge of industrial wastes into the sewer system. The characteristics of sewage waste waters obtained from different cities, are presented in Table 1. On an average, the sewage of Indian cities contains 50 ppm of nitrogen, 15 ppm of phosphorus and 30 ppm of potassium. Sludge on an average contains 1.5 to 3.5 per cent N, 0.75 to 4 per cent P_2O_5 and 0.3 to 0.6 per cent K_2O .

Water being a scarce commodity there is a need to treat the waste waters for reusing it and preventing the cause of pollution. There are several methods available for the treatment of the domestic waste waters.

Activated sludge process consists of aerating the sewage either by diffusion or by mechanical means. The activated sludge (biological floc) harbours micro-organisms, which decompose organic substances present in the sewage aerobically. Sludge is separated from the effluents in a settling tank after a suitable interval. An overall reduction of 85–95 per cent of suspended solids and BOD and 90 to 98 per cent reduction in bacteria could be obtained through the use of this method combined with primary treatment. The effluent thus obtained usually has suspended solids of 20 ppm, which is well within safe limits.

Trickling filtration process involves distribution of sewage on a bed of inert material, like bricks, coke and sand. The organisms growing on the surface of these solids as slimy films act as purifying agents. This process is more effective in treatment of industrial effluents.

After the removal of the solid portion or sludge, sewage water is known as treated effluent and is used for purposes of irrigation and fertilization. Since available sewage and sullage water are in quite a concentrated form, its dilution with the raw water in the proportion 1:1 has been found to be beneficial. The raw water may either be from well, tube-well or river. Sewage and sullage waters have been estimated to give 30 to 50 per cent increase in yield of food crops and 100 per cent increase in fodder yield as compared with ordinary irrigation water. But as sewage may contain harmful bacteria, the growing of food crops that are eaten rather raw or low-lying vegetables such as tomatoes, radish, onion, garlic, carrot, etc. is not recommended on sewage farms. Fodder crops like oats, berseem and lucerne, cereals like rice, wheat, *bajra*, *jowar* etc., fruit trees like papaya, banana, etc. and sugar-cane, used for *gur* or sugar-making but not for chewing, and vegetables eaten in a cooked form could be grown with considerable profit. The

ORGANIC MANURES, THEIR NATURE AND CHARACTERISTICS

TABLE 1. CHEMICAL CHARACTERISTICS OF SEWAGE FROM INDIAN CITIES

City	pH	Total solids (ppm)	Dissolved solids (ppm)	Suspended solids	Total N (ppm)	P ₂ O ₅ (ppm)	K ₂ O (ppm)	Cl- (ppm)	BOD 9 (5 days) 20 C (mg/l)
Aligarh	9.0	1470	955	515	55	16	2	205	260
Kanpur	7.0	1500	900	600	50	15	40	85	250
Hissar	7.8	1985	1910	75	58	14	72	500	370
Nagpur	7.2	1200	1000	200	60	20	45	30	350
Mysore	6.9	890	570	315	29	13	41	3	—
Madras	7.3	1700	1200	500	60	22	55	254	350
Tuticorin	6.8	1480	1240	240	56	10	—	392	420

ORGANIC MANURES

vegetable crops generally grown with sewage irrigation are cabbage, cauliflower, turnip, potatoes, brinjal, lady's fingers, beans and leafy vegetables.

Point of Caution. The municipal sewage may also contain high concentrations of heavy metals which may prove toxic to plants. The elements of general concern are B, Cd, Co, Cr, Cu, Hg, Ni, Pb, Se and Zn. The presence of large quantity of heavy metals in sullage such as Zn, Cu, Ni, Cd, Pb and further pollution with industrial organic wastes makes them unsuitable for land application. Cadmium is one of the elements that is taken up by most crops and accumulates in plants and thus endangers animal and human health. The excessive amounts of these metals are added into sewage through discharge of industrial wastes without pre-treatment. These elements can be toxic to plants grown on sewage amended soils or to the animals which consume these plants. In view of this, it is important to monitor the build-up of heavy and toxic substances which commonly occur in sewage/sullage and pose serious hazard to plants.

III. LIVESTOCK AND HUMAN WASTES — CHARACTERISTICS AND MANURIAL VALUE

KNOWLEDGE of livestock waste characteristics is fundamental to the development of feasible waste management and their efficient utilization. Basic information on the frequency of animal manure excretion, quantity of manure and their characteristics permits specific recovery of waste components, by-product development, fertilizer value and reuse of manure as animal feed and as soil conditioner. The term livestock waste means (i) fresh excrement including both solid and liquid portions, (ii) total excrement, including the bedding material, litter to absorb the liquid component, (iii) the material after liquid run-off, evaporation of water and other volatile components and leaching of soluble nutrients, and (iv) material obtained following aerobic or anaerobic storage of livestock manure.

The feasible approach to characterize livestock waste is to obtain random samples of the solid and liquid waste and analyse for their ingredients. To determine the relationship between animal feed intake and waste characteristics, nutritional trials are conducted and the quantity and quality of the wastes are estimated. The results obtained from nutritional trials are accurate but this is a time-consuming and costly process. The quantity and quality of the wastes are characterized after finding out the digestibility coefficients for the feed components, viz., organic matter, crude fibre, nitrogen free extract, ether extract, crude protein, and after working out the mineral balance in the animals, viz. nitrogen, phosphorus, potassium, calcium and magnesium. Many nutritional trials have been conducted with different livestock like cattle, buffalo, goat, poultry, pig, etc. in national laboratories, veterinary and animal science colleges of agricultural universities in India which can form the basis for assessing the livestock waste characteristics.

The characteristics of livestock wastes are functions of the digestibility, composition of the feed ration and the species of animals and their physiology. The wastes from ruminants such as cattle, buffalo, goat and sheep have a different composition than the wastes obtained from pigs and poultry which are highly digestible. The faeces of livestock consist chiefly of undigested food which has escaped bacterial and digestive enzyme action. Faeces also contain residue from digestive fluids, waste mineral matter, worn-out cells from the intestinal linings, mucus, bacteria and foreign matter such as dirt consumed alongwith food. Undigested protein is excreted in the faeces

ORGANIC MANURES

and the excess nitrogen from the digested protein is excreted in the urine as uric acid or urea. Potassium is absorbed during digestion but eventually most of it is excreted through urine. Calcium, magnesium, iron and phosphorus are excreted mostly in the faeces.

A number of methods are used to describe the characteristics of livestock wastes. They can be described on the basis of pollutional nature in terms of B.O.D. (Biological oxygen demand), C.O.D. (Chemical oxygen demand), solids per cent, volatile matter content, nutrient and fertilizer value. The data normally available pertains to the quantity of solid or liquid or combined manure in terms of kg or litre per animal per day. This method of quantification is most realistic in estimating the gross wastes generated at a particular livestock production unit. Besides, other parameters like available nutrient content in terms of fertilizer value, viz. nitrogen, phosphoric acid and potassium oxide can also be determined depending upon the utility of the waste. Livestock wastes are generated as a semi-solid and has to be handled and utilized in this condition. However, liquid or slurry waste system has been considered where the waste can be handled as liquid and transported by pumps and spreaders (Loehr, 1974).

The available information on the quantitative and qualitative nature of livestock excreta should be used to assess and to develop order of magnitude information concerning the potential livestock waste availability. Although it is difficult to apply average livestock waste production values to a specific location, knowledge of average values is very useful for assessing the potential of these wastes and their effective utilization. Hence, the quantity of manure excretion, their characteristics for different livestock from the available literature of metabolism and nutritional trials will be considered.

Bovine Manure. For accurate quantitative assessment of cattle and buffalo dung and urine excretion and their characteristics, the results of nutritional trials conducted at National Dairy Research Institute, Karnal and Indian Veterinary Research Institute, Izatnagar on Sahiwal and Tharparkar cattle and Murrah buffaloes were taken into consideration (Daniel *et al.*, 1967, 1968; Gopal Krishna, 1971; Iyer and Ayyar, 1938; Krishna Singh and Mudgal, 1967; Mudgal, 1963; Mudgal and Ray, 1965, 1967; Sebastian, 1967; Sharma, 1968; Singh, 1964; Verma, 1966). The dry matter intake, digestibility, quantity of dung and urine excreted and the nitrogen, phosphorus and potassium balance were obtained to assess the quantitative and qualitative nature of the cattle manure.

The quantity of wet dung and urine excreted by Sahiwal and Tharparkar cattle and Murrah buffaloes is presented in Tables 2 to 4. These Tables provide the information on dry matter intake, dry matter excreted, wet dung and urine produced per day depending on the body weight in respect of different

LIVESTOCK AND HUMAN WASTES — CHARACTERISTICS AND MANURIAL VALUE

groups of cattle and buffaloes, viz. male calf, heifer, dry and lactating cows and buffaloes. The range of the above parameters depending on body weight, etc. can be seen in Tables 2-4.

TABLE 2. QUANTITY OF WET DUNG AND URINE EXCRETED PER DAY BY SAHIWAL CATTLE

Group of cattle	Body weight (kg)	Dry matter Intake (kg)	Dry matter excreted (kg)	Wet dung (kg)	Urine (l)
Male calf	140	3.226	1.302	6.960	3.725
	170	3.906	1.632	8.342	5.675
	190	3.928	1.491	7.144	6.595
	210	4.399	1.615	8.372	5.803
	240	4.429	1.824	9.583	5.426
	250	5.129	1.886	9.430	6.25
	260	5.488	1.808	9.040	8.757
	275	5.550	2.037	10.190	10.914
Heifer	170	4.235	1.560	6.425	5.620
	200	5.505	1.866	10.610	9.950
	225	6.125	1.958	10.435	9.565
	250	6.250	2.180	10.525	11.590
Dry cow	325	5.120	1.920	7.760	10.350
	350	5.325	1.995	8.335	12.960
	375	5.576	2.191	8.760	11.155
	420	6.025	2.250	9.090	12.550
Lactating cow	350	9.560	3.850	22.140	14.120
	375	10.401	4.537	26.650	17.580
	400	11.525	4.755	31.860	21.875

TABLE 3. QUANTITY OF WET DUNG AND URINE EXCRETED PER DAY BY THARPARKER CATTLE

Group of cattle	Body weight (kg)	Dry matter Intake (kg)	Dry matter excreted (kg)	Wet dung (kg)	Urine (l)
Male calf	120	3.896	1.780	8.825	7.560
	170	3.418	1.520	7.608	6.920
	200	4.227	1.680	8.420	7.455
	225	4.264	1.863	9.325	7.925
Heifer	170	4.125	1.925	9.650	9.820
	190	4.879	2.050	9.325	8.525
	220	5.129	2.105	10.320	11.910
	240	5.425	2.125	10.825	14.105
Dry cow	380	4.250	1.950	6.525	8.740
	400	4.511	2.066	7.170	10.230
	420	4.820	2.250	7.435	12.265
Lactating cow	270	9.875	4.525	22.495	13.805
	385	8.957	4.425	21.530	11.640
	400	10.546	4.561	22.250	13.145
	420	11.250	4.625	25.730	14.570

ORGANIC MANURES

TABLE 4. QUANTITY OF WET DUNG AND URINE EXCRETED PER DAY BY MURRAH BUFFALO

Group of buffalo	Body weight (kg)	Dry matter Intake (kg)	Dry matter excreted (kg)	Wet dung (kg)	Urine (l)
Male calf	100	2.856	1.420	5.465	3.690
	125	3.250	1.580	6.794	5.205
	150	3.950	2.050	9.510	5.710
	200	4.476	2.105	10.255	8.910
	250	4.911	2.280	11.560	9.515
Heifer	100	4.665	1.450	6.880	4.515
	150	5.445	2.022	7.425	6.183
	250	5.525	2.125	9.125	7.500
	300	5.975	2.314	11.570	9.025
Dry buffalo	350	4.805	2.050	10.380	6.810
	400	6.025	2.994	16.025	7.120
	500	6.525	3.225	17.120	7.605
	580	7.387	3.466	21.216	10.260
	400	7.282	3.420	17.705	10.250
Lactating buffalo	450	8.932	3.572	20.250	11.527
	500	9.520	3.625	24.705	13.510
	550	9.250	3.420	20.305	13.120
	575	13.560	4.977	27.985	14.825
	600	14.905	5.349	28.745	14.250
	625	15.350	5.477	30.250	15.650

The lactating cattle and buffaloes, in general, had the highest dry matter intake as also more excretion of dung and urine. This was followed by dry animals, heifers and male calf. The excretion coefficient of the feed will depend on the nutritive value and digestibility of the dry matter (Sen, 1957). Even though, the digestibility of the feed consumed by the animal depends on the nature of the feed, it was observed that the Tharparkar breed had the higher excretion coefficient. In the case of Murrah buffalo, the male calves and the non-lactating buffaloes have higher excretion coefficient. The moisture content of the dry dung is a function of type of feed, environmental temperature and humidity. So, the moisture content of the feed, water intake and the season influence the quantity of wet dung and urine excreted.

The composition of the organic fractions in the dung as well as the C : N ratio are presented in Table 5. The dung consisted of about 75 to 85 per cent moisture, 15 to 25 per cent organic matter and 2 to 5 per cent mineral matter. The organic matter of dung mainly comprised of 78 to 90 per cent of total carbohydrates (crude fibre + nitrogen free extract), 9 to 18 per cent of crude protein and 2 to 5 per cent ether extract (Neelakantan and Singh, 1975). In the case of Sahiwal cattle, the excretion coefficient of crude fibre varied from 20.8 to 44.8 per cent, whereas that of nitrogen free extract varied from 30.4 to 48.2 per cent. In the case of Murrah buffaloes,

TABLE 5. COMPOSITION OF DUNG EXCRETED BY DIFFERENT AGE GROUPS OF SAHIWAL CATTLE AND MURRAH BUFFALOES

Group of animal	Body wt. (kg)	Feed used	Dry matter excreted (kg)	Organic matter excreted (kg)	Per cent composition			C:N ratio
					Ether extract	Crude fibre	Nitrogen free extract	
A. Cattle								
1. Male calf	200	Oats silage + wheat straw	1.530	1.334	4.35	23.01	58.54	14.10 25.67
2. Heifer	220	Hybrid napier	2.023	1.316	3.30	15.00	64.98	16.72 21.70
3. Milch cow	370	Berseem	4.479	3.200	4.53	30.18	52.73	12.56 28.85
4. Dry cow	350	Berseem + oat straw	2.128	1.702	3.32	29.52	53.50	13.66 26.54
B. Buffalo								
1. Male calf	240	Wheat <i>bhusa</i>	2.128	1.822	2.35	19.81	68.95	8.89 40.77
2. Heifer	260	Lucerne hay	2.134	1.895	3.01	24.17	54.30	18.52 19.57
3. Milch buffalo	580	Maize + lucerne hay	4.602	4.309	3.25	9.70	73.36	13.69 26.48
4. Dry buffalo	434	Wheat straw + <i>jowar</i>	3.018	2.577	1.59	22.89	68.33	7.18 49.83

ORGANIC MANURES

the excretion coefficient of crude fibre varied from 20.2 to 37.3 per cent, whereas that of nitrogen free extract varied from 35.3 to 56.8 per cent. In the case of lactating Sahiwal cattle, the excretion coefficient of crude protein was only 17.3 per cent, whereas in Murrah buffalo it was 30.8 per cent. The C:N ratio of the dung for cattle and buffalo varied from 19.57 to 49.83 depending upon the feed material. With berseem feeding the C:N ratio of dung excreted by Sahiwal lactating cattle was 28.85, whereas with lucerne hay feeding the buffalo heifer excreted dung with a C:N ratio of 19.57. With wheat *bhusa* feeding, the buffalo male calves excreted dung with a C:N ratio of 40.77, whereas with wheat straw and *jowar* feeding, the dry buffalo excreted dung with a C:N ratio of 49.83. Hence, a higher C:N ratio was observed with feeding of *bhusa* or straw rather than with green fodder.

The nitrogen and phosphorus balance of Sahiwal and Tharparkar cattle and Murrah buffaloes is presented in Table 6. The excretion of nitrogen through dung varied from 38 to 53 per cent of the total nitrogen excretion. In the lactating cattle, where the nitrogen-outgo through milk was of the order of 18.3 per cent, the N-outgo through dung was 19.7 per cent. In the case of lactating Murrah buffalo with 20.3 per cent N-outgo through milk, the N-outgo through dung was 37.4 per cent and 42.3 per cent through urine. The phosphorus excretion through dung varied from 89 to 98 per cent of the total P-excreted. In the case of lactating animals with 23 to 36 per cent P-outgo through milk, the dung P-outgo ranged from 63 to 79 per cent only (Table 6). The excretion of nitrogen and phosphorus not only depended on their intake by animals but also on the age-group of animal, on the season and the metabolic body size of the animal.

The potassium oxide excretion is normally not reported in metabolism trials but the available data pertains to male calves and bullocks only (Table 7). The outgo of K_2O through dung varies from 8 to 17 per cent only of the total K_2O excretion, whereas the urine contains most of the potash excreted.

Goat and Sheep Excreta. The goat with a body weight of 20 and 40 kg excretes 0.320 to 0.625 kg dung and 0.374 to 0.498 litres urine, whereas the sheep with a body weight of 25-40 and 50-60 kg excreted 0.370 to 1.430 kg dung and 0.350 to 0.950 litres urine per head per day. The chemical composition of their excreta showed that dung had a dry matter content of 42 to 48 per cent which constituted 46-51 per cent of the dry matter intake. The organic fraction of the dung comprised 5.2 to 9.3 per cent crude protein, 1.4 to 1.9 per cent ether extract, 27.8 to 36.4 per cent crude fibre, 40 to 47 per cent nitrogen free extract and 0.35 to 0.77 per cent ash (Goering and Smith, 1977).

The excretion of nitrogen and phosphorus in goat dung and urine is presented in Table 8 and that of nitrogen, phosphorus and potash of sheep

TABLE 6. NITROGEN AND PHOSPHORUS EXCRETION IN DIFFERENT AGE GROUPS OF SAHIWAL MILCH BREED OF CATTLE AND MURRAH BUFFALOES

Group of animal	Nitrogen (g)				Phosphorus (g)					
	Intake	Total excretion	In dung	In urine	In milk	Intake	Total excretion	In dung	In urine	In milk
A. Cattle										
1. Male calf	88.7	76.8	29.9 (38.9%)	46.9 (61.1%)	—	12.8	8.2	7.7 (93.9%)	0.5 (6.1%)	—
2. Heifer	137.0	131.0	50.0 (38.1%)	81.0 (61.9%)	—	5.5	2.57	2.5 (97.3%)	0.07 (2.7%)	—
3. Milch cow	376.5	372.0	73.8 (19.7%)	231.2 (62.0%)	67.9 (18.3%)	45.5	38.33	24.09 (63.2%)	0.37 (0.9%)	13.77 (35.9%)
4. Dry cow	96.0	95.0	39.0 (41.0%)	56.0 (59.0%)	—	9.60	8.41	8.11 (96.8%)	0.3 (3.2%)	—
B. Buffalo										
1. Male calf	84.4	64.0	26.0 (40.6%)	38.0 (59.4%)	—	5.85	5.03	4.9 (97.4%)	0.13 (2.6%)	—
2. Heifer	146.2	134.0	56.0 (41.8%)	78.0 (58.2%)	—	6.94	2.57	2.5 (97.3%)	0.07 (2.7%)	—
3. Milch buffalo	305.0	264.6	99.0 (37.4%)	112.0 (42.3%)	53.6 (20.3%)	53.6	44.10	33.5 (75.9%)	0.3 (0.8%)	10.3 (22.3%)
4. Dry buffalo	72.2	56.4	29.8 (52.8%)	26.6 (47.2%)	—	13.9	6.2	5.5 (88.7%)	0.7 (11.3%)	—

Figures within parenthesis indicate the % excretion of the mineral through dung, urine and milk.

TABLE 7. EXCRETION OF POTASH IN CATTLE

S. No.	Group of animal	Feed used	Body weight (kg)	K ₂ O in g/day		
				Intake	Total Outgo	Dung Urine
1.	Male calf	Guinea grass	100	29.35	25.13	2.76
			150	37.73	31.89	3.57
			200	46.59	45.27	7.88
			250	47.83	41.82	9.81 (15.8%)
2.	Bullock	Ragi straw	—	83.05	74.00	6.23 (8.4%)
		Bolaram hay	—	25.25	22.00	3.70
						18.30 (83.2%)

Figures within parenthesis indicate the percentage excretion of K₂O through dung and urine.

TABLE 8. THE EXCRETION OF NITROGEN AND PHOSPHORUS IN GOAT DUNG AND URINE/HEAD/DAY

Expt No.	Body wt. (kg)	Nitrogen (g)		Phosphorus (g)	
		Intake	Urine	Dung	Urine
1.	29—34	6.00—9.40	3.01—6.00	1.01—1.90	0.01
2.	35—40	8.50—16.80	4.80—6.20	1.18—2.46	0.02—0.04

TABLE 9. THE EXCRETION OF NITROGEN, PHOSPHORUS AND POTASH IN SHEEP DUNG AND URINE (G)/HEAD/DAY

Expt. No.	Body wt. (kg)	D.M. intake (g)	N		P		K				
			Intake	Dung	Urine	Intake	Dung	Urine			
1.	38—45	500	21.8— 23.6	3.8— 4.8	12.8— 17.1	2.20— 2.83	1.97— 2.60	0.03— 0.12	15.7— 24.8	0.1— 0.9	14.4— 20.4
2.	36—50	800	34.9— 37.8	5.8— 6.7	20.6— 27.2	3.52— 4.48	2.73— 3.30	0.03— 0.05	25.2— 39.6	0.8— 2.1	21.8— 28.4
3.	36—40	—	4.4— 16.25	2.88— 6.41	2.63— 7.73	0.51— 11.61	0.96— 10.15	0.02— 0.13	—	—	—
4.	Adult	—	41.3— 47.8	7.1— 12.0	20.6— 24.6	2.55— 2.75	1.5— 2.3	0.03— 0.07	—	—	—

excreta is presented in Table 9. It was observed that the dung comprised 30 to 50 per cent total nitrogen excretion, all phosphoric and 90.95 per cent of potassium (Bhandari and Gupta, 1972 ; Ulyatt and Machae, 1974). In castrated ram, the urination was observed less than once per hour and yielded 150 ml per urination. The total output of urine ranged from 1700 to 2000 ml/day/head. The urine comprised mainly 68.85 per cent of urea-N and 11.16 per cent ammonia-N. The average composition of N, P_2O_5 and K_2O in goat and sheep dung comprised 0.65 per cent, 0.5 per cent and 0.03 per cent and that in urine 1.70 per cent, 0.02 per cent and 0.25 per cent, respectively.

Pig and Hog Excreta. The quantity of dung and urine excreted by hogs of 10 to 50 kg body weight ranged from 0.5 to 2.5 kg and 1.3 to 4.0 litres/head/day respectively, whereas the excretion of dung and urine by hogs of 51 to 90 kg body weight ranged from 1.6 to 4.5 kg and 2.9 to 4.0 litres/head/day respectively. The quantity of excretion of dung and urine by pigs of a body weight of 33 to 45 kg ranged from 0.57 to 1.57 kg and from 2.1 to 3.6 litres/head/day respectively.

The moisture content of hog and pig manure ranged from 69.5 to 76.7 per cent. The average excretion of hog manure was about 6.8 per cent of the body weight/hog/day. The dung excreted by pigs and hogs contained 0.60 per cent N, 0.50 per cent P_2O_5 and 0.20 per cent K_2O , whereas urine comprised 0.40 per cent N, 0.10 per cent P_2O_5 and 0.50 per cent K_2O . One tonne of hog manure or 265 gallons contained 14 lb N, 8 lb P_2O_5 and 8 lb K_2O .

Poultry Excreta. This is a rich organic manure, since liquid and solid excreta are excreted together. The excreta from hen 1 to 6 months old ranged from 229 to 888 g/head/day depending on the age, etc. (Morino, 1975). The poultry excreted about 5 per cent of its body weight/day. The chicken up to 13-week age on an average excreted about 274 g/head/day. The chemical composition of the fresh poultry excreta of adult layers is given by Jai Kishan and Hussain (1977). The dry matter content of the fresh poultry excreta ranged from 20-30 per cent and it comprised 20.2 per cent ash. The organic fraction of the excreta contained 21.5 per cent crude protein, 1.9 per cent ether extract, 13.4 per cent crude fibre and 42.9 per cent nitrogen free extract.

The manurial constituents of the poultry excreta are given by Garner (1967). The fresh poultry excreta comprised 80 per cent moisture, 0.76 per cent N, 0.63 per cent P_2O_5 and 0.22 per cent K_2O , whereas the partly dried and kiln dried excreta had only 30 and 10 per cent moisture respectively and 4 to 5 times of the above nutrients. The deep litter with sawdust and straw comprised 1.8 per cent N, 2.3 per cent P_2O_5 and 1.4 per cent K_2O .

ORGANIC MANURES

Nitrogen excretion by adult layers ranged between 0.65 and 0.75 g against nitrogen intake of 2.65 and 2.90 g/head/day whereas the phosphorus excretion showed a narrow range of 0.36 to 0.39 g against an intake of 0.62 to 0.70 g/head/day.

Human Excreta. The daily per capita production of suspended solids in human excreta ranged from 0.135 to 0.270 kg/head/day (Gotaas, 1956). The composition of nightsoil collected from Central Prison, Nagpur analysed by NEERI, 1976 is as follows :

moisture 86.7 per cent, total solids 13.3 per cent, volatile solids 11.6 per cent, nitrogen 4.0 per cent, phosphorus 1.53 per cent and potassium 1.08 per cent. The urine excretion of human beings ranged from 0.5 to 3.0 litres/head/day and the average excretion of wet faeces was 0.234 kg/head/day. An estimation of the manurial value of faeces and urine of human beings showed that 2.10 g N, 1.64 g P_2O_5 and 0.73 g K_2O /person/day was excreted and the corresponding values for urine were 12.10, 1.80 and 2.22 g/person/day.

IV. AVAILABLE POTENTIAL OF ORGANIC MATERIALS AND PLANT NUTRIENTS

THE IMPORTANCE of agricultural wastes in general and agro-industrial products in particular has been recognised during the recent years and literature on Indian local organic resources and their possible utilisation has been compiled (Anonymous, 1974; Gaur, 1978, 1979).

Organic Resources and Potential. India has vast potential of manurial resources and major resources are listed below :

A. Livestock and human wastes

- (i) Cattle-shed wastes such as cattle and buffalo dung, and urine.
- (ii) Other livestock and human excreta.
- (iii) Byproducts of slaughter-houses and animal carcasses : Blood and meat wastes, bones, horns and hooves, leather and hair wastes.

B. Crop residues, tree wastes and aquatic weeds

- (i) Crop wastes of cereals, pulses and oilseeds (wheat, paddy, *bajra*, *jowar*, gram, *moong*, *urad*, cowpea, *arhar*, *masoor*, ground-nut, linseed, etc.).
- (ii) Stalks of corn, cotton, tobacco, sugar-cane trash, leaves of cotton, jute, tapioca, arecanut, tree leaves, water hyacinth, forest litter, etc.

C. Green manure. Sunnhemp (*Crotalaria juncea*), *dhaincha* (*Sesbania aculeata*), cluster beans (*Cyamopsis tetragonoloba*), *senji* (*Melilotus parviflora*), cowpea, (*Vigna catjang*), horse-gram (*Dilichos biflorus*), pillipeasara (*Phaseolus trilobus*), berseem (*Trifolium alexandrinum*), etc.

D. Urban and rural wastes

- (i) Rural and urban solid wastes.
- (ii) Urban liquid wastes—sewage and sullage.

E. Agro-industries byproducts. (i) oil-cakes, (ii) paddy husk and bran, (iii) bagasse and pressmud, (iv) sawdust, (v) fruit and vegetable wastes, (vi) cotton, wool and silk wastes, and (vii) tea and tobacco wastes.

F. Marine wastes. Fish meal and seaweeds.

G. Tank silts.

Livestock Wastes

Cattle and Buffalo Dung. The estimate of annual production of bovine dung in India on the basis of Livestock Census, 1966 was estimated to be 344.5 million tonnes (Goel *et al.*, 1973) and 1335 million tonnes (NCAER, 1965). Garg *et al.* (1971) reported that the bovine urine production was approximately 370 million tonnes per annum. But no systematic survey

ORGANIC MANURES

was conducted to estimate the dung and urine excretion in India. Hence, an attempt has been made to formulate a relationship between the dung excretion and feed intake as well as urine excretion on the basis of feed availability for cattle and buffaloes. The quality of wet dung and urine excreted by 178.865 million cattle and 57.941 million buffaloes was assessed on the basis of the feed availability data reported from the pilot surveys conducted by IARS, Delhi

The digestibility coefficients of different feeding materials in metabolism trials were worked out for the green and dry fodder and concentrate, taking into consideration their dry matter content. The excretion coefficient was calculated on the basis of 100 per cent digestibility coefficient and the moisture content of the dung has been taken as 80 per cent. The dung excretion formula was calculated by taking the digestibility coefficient of 65 per cent for green fodder, 55 per cent for dry fodder and 70 per cent for concentrate feeding from the available literature on nutritional trials conducted at NDRI, Karnal and IVRI, Izatnagar and other trials (Sen, 1953).

The relationship of feed intake to wet dung excretion is given below :

Wet dung (kg) = 0.525 green fodder + 2.25 dry fodder + 1.5
concentrate (kg).....I

Further the quantity of urine excreted was studied and the relationship between urine and dung excretion and dry matter intake was worked out for cattle and buffalo.

Urine (l) = 0.677 × wet dung (kg).....II

Urine (l) = 1.52 × dry matter intake (kg).....III

1.03

By using the above formulae for urine and dung excretion and the feed availability in India, the excretion pattern for cattle and buffalo in different states of India was calculated.

From the total annual excretion of dung and urine from both cattle and buffaloes, their potentiality of the plant nutrients was worked out taking an average N, P₂O₅ and K₂O content of dung and urine as follows :

Wet dung : N = 0.15 %, P₂O₅ = 0.1 %, K₂O = 0.05 %

Urine : N = 0.20 %, P₂O₅ = 0.01 %, K₂O = 0.20 %

The total organic matter of the bovine excreta was calculated taking the dry matter content of dung as 20 per cent and the organic matter content as 94 per cent of the dry matter.

The daily feed availability for cattle and buffalo in different states of India was reported (IARS, 1956-67). The average feed availability for Indian cattle was worked out to be 3.311 kg green fodder, 4.134 kg dry fodder and 0.186 kg concentrate. The daily feed availability for buffaloes in India was worked out to be 4.10 kg green fodder, 4.08 kg dry fodder and 0.177 kg con-

AVAILABLE POTENTIAL OF ORGANIC MATERIALS AND PLANT NUTRIENTS

centrate. It was observed that in the northern states like Punjab, Haryana and Union Territories of Delhi and Chandigarh, the adult females are fed with 9.10 to 9.25 kg green fodder for cattle and 11.05 to 13.0 kg for buffaloes. But, moderate green fodder supply to adult female cattle and buffaloes was observed in Rajasthan, Bihar, Assam, Jammu and Kashmir and Uttar Pradesh. In other states, where less green fodder is available, more of dry fodder (*bhusa* and hay) was given. In the case of Kerala the lowest feeding of both green and dry fodder was observed.

The average daily outturn of wet dung from the different groups of cattle and buffaloes in different states of India is presented in Table 10. The

TABLE 10. DAILY OUTTURN OF WET DUNG PER ANIMAL FOR DIFFERENT AGE-GROUPS OF CATTLE AND BUFFALOES IN INDIA (KG)

S. No.	State	Cattle				Buffalo			
		Y.S.	A.F.	A.M.	Average per cattle	Y.S.	A.F.	A.M.	Average per buffalo
1.	Andhra Pradesh	3.97	7.60	18.23	11.41	3.36	9.84	20.00	10.20
2.	Assam	7.03	12.60	11.70	10.52	6.23	13.05	17.38	13.32
3.	Bihar	4.44	8.85	11.37	8.50	8.03	20.49	7.13	13.91
4.	Gujarat	3.95	8.21	15.90	10.77	4.82	13.46	18.16	9.59
5.	Haryana	8.19	21.04	25.25	17.54	7.76	24.88	26.33	16.95
6.	Himachal Pradesh	8.19	21.04	25.25	18.56	7.76	24.88	26.33	19.44
7.	Jammu and Kashmir	7.03	12.60	11.70	10.51	6.23	13.05	17.38	9.54
8.	Kerala	1.00	5.15	5.63	3.62	0.92	7.50	4.93	4.96
9.	Karnataka	5.83	11.86	15.02	11.59	4.88	12.51	12.61	10.09
10.	Madhya Pradesh	3.77	7.26	8.02	6.40	4.62	12.17	10.10	8.96
11.	Maharashtra; Goa, Daman, Diu	8.38	16.30	21.65	16.74	9.69	19.54	21.07	16.68
12.	Nagaland	4.52	10.32	12.31	8.94	6.38	18.50	10.73	12.32
13.	Orissa	4.62	11.85	13.41	10.61	5.13	15.94	14.31	12.73
14.	Punjab	8.19	21.04	25.25	18.58	7.76	24.88	26.33	14.66
15.	Rajasthan	5.76	14.09	16.63	12.30	6.20	18.28	18.22	12.71
16.	Tamil Nadu	4.01	16.64	17.36	14.37	4.78	16.70	20.42	13.62
17.	Uttar Pradesh	4.59	9.19	19.22	13.20	4.97	14.12	14.88	10.99
18.	West Bengal	4.52	10.32	12.31	9.53	6.38	18.50	10.73	12.15
19.	Andaman and other Islands	1.00	5.15	5.63	3.83	0.92	7.50	4.93	4.82
20.	Chandigarh	6.27	19.64	24.24	15.32	6.18	28.43	16.09	20.55
21.	Delhi	6.27	19.64	24.24	17.38	6.18	28.43	16.09	20.24
22.	Manipur	4.52	10.32	12.31	9.27	6.38	18.50	10.73	12.13
23.	Pondicherry	4.01	16.64	17.36	13.09	4.78	16.70	20.42	13.11
24.	Tripura, Meghalaya, Mizoram	4.52	10.32	12.31	8.69	6.38	18.50	10.73	12.92
All-India Average		4.90	11.26	15.59	11.33	5.67	14.78	14.86	11.60

Y.S. = Young stock; A.F. = Adult female; A.M. = Adult male

ORGANIC MANURES

highest excretion rate of more than 15 kg dung per animal was noticed in Haryana, Punjab, Himachal Pradesh, Maharashtra, Delhi and Chandigarh. The lowest excretion rate of 3.62 to 4.96 kg dung per animal was recorded from Kerala. The all-India average daily dung excretion pattern in kg for cattle and buffalo groups is given below :

Cattle: Young stock=4.90; adult female=11.26 and adult male=15.59; Buffaloes: Young stock=5.67, adult female=14.78 and adult male=14.86 (Neelakantan, 1975). But excretion rate of 2.9 to 7.0 kg in different states in India was reported by Goel *et al.* (1973) from the IARS survey on the estimate of dung evacuated only in the households, and in this study, the quantity of dung evacuated out in grazing fields and roadside was excluded.

Table 11 presents the daily outturn of urine from different groups of

TABLE 11. DAILY OUTTURN OF URINE FROM DIFFERENT AGE-GROUPS OF CATTLE AND BUFFALOES IN INDIA (IN LITRES)

S. No.	State	Cattle				Buffalo			Average per buffalo
		Y.S.	A.F.	A.M.	Average per cattle	Y.S.	A.F.	A.M.	
1.	Andhra Pradesh	3.30	4.70	10.38	6.88	3.40	6.33	11.34	6.49
2.	Assam	6.09	8.12	6.94	7.04	5.69	8.54	10.44	8.70
3.	Bihar	2.97	5.94	6.60	5.43	6.94	13.01	4.04	9.40
4.	Gujarat	3.35	5.11	9.14	6.57	4.10	8.11	10.65	6.50
5.	Haryana	6.04	13.82	20.50	11.55	6.89	16.01	16.06	11.82
6.	Himachal Pradesh	7.28	13.52	15.17	12.13	7.01	15.92	16.16	13.16
7.	Jammu and Kashmir	6.15	8.08	6.98	7.11	6.64	8.67	10.59	8.42
8.	Karnataka	4.97	7.47	8.61	7.27	4.19	7.87	7.30	6.63
9.	Kerala	0.89	3.34	3.30	2.45	0.67	5.23	3.12	3.30
10.	Madhya Pradesh	3.19	4.50	4.72	4.14	3.87	7.70	5.94	5.93
11.	Maharashtra; Goa, Daman, Diu	7.04	10.03	12.35	10.32	8.28	12.32	11.92	10.99
12.	Nagaland	3.90	6.51	7.17	5.82	5.51	11.68	6.25	7.95
13.	Orissa	4.12	7.64	8.23	6.95	4.03	10.16	8.48	8.26
14.	Punjab	7.26	13.58	15.14	12.11	6.87	16.28	16.21	12.76
15.	Rajasthan	5.04	8.98	10.03	8.04	5.34	11.74	10.77	9.05
16.	Tamil Nadu	6.21	10.29	9.94	8.73	4.00	10.56	11.46	8.62
17.	Uttar Pradesh	3.99	5.81	11.26	8.15	4.32	8.93	8.91	7.31
18.	West Bengal	4.02	6.34	7.35	6.09	5.67	12.21	6.21	7.78
19.	Andaman and Nicobar Islands, (Dadra, Nagar Haveli; Laccadive, Minicoy; Amindive Islands)	0.90	2.47	3.38	2.04	0.65	9.37	4.11	4.65
20.	Chandigarh	9.22	11.82	14.19	10.45	6.25	19.05	9.80	14.85
21.	Delhi	8.65	13.11	14.56	11.16	5.75	18.32	9.71	13.53
22.	Manipur	4.09	6.09	7.15	5.92	4.08	12.01	7.32	8.40
23.	Pondicherry	3.40	9.96	9.71	8.13	4.85	11.35	14.02	9.81
24.	Tripura, Meghalaya, Mizoram	4.06	6.65	7.37	5.63	6.15	9.51	7.61	8.85
All-India Average		4.24	7.09	9.10	7.36	4.96	10.01	8.63	8.02

Y.S. = Young stock; A.F. = Adult female; A.M. = Adult male

AVAILABLE POTENTIAL OF ORGANIC MATERIALS AND PLANT NUTRIENTS

cattle and buffaloes in India. The average excretion of urine/day/cattle and buffalo was 7.36 and 8.02 litres, respectively. The urine excretion/day/cattle was 4.24, 7.09 and 9.10 litres for young stock, adult female and adult male respectively. But the corresponding urine excretion value/day/buffalo was 4.96, 10.01 and 8.63 litres.

Table 12 presents the statewise annual outturn of wet dung and urine from different groups of cattle and buffaloes in India. The annual excretion

TABLE 12. ANNUAL OUTTURN OF WET DUNG AND URINE FROM CATTLE AND BUFFALOES IN INDIA

S. No.	State	Annual wet dung (Million tonnes)			Annual urine excretion (Million tonnes)		
		Cattle	Buffalo	Total	Cattle	Buffalo	Total
1.	Andhra Pradesh	52.309	25.080	77.389	32.350	17.219	49.569
2.	Assam	22.368	3.008	25.376	15.131	2.087	17.218
3.	Bihar	49.355	19.202	68.557	30.440	13.001	43.441
4.	Gujarat	25.496	12.760	38.262	15.949	8.475	24.424
5.	Haryana	16.644	15.569	32.213	10.647	11.189	21.836
6.	Himachal Pradesh	15.283	3.898	19.181	9.923	2.692	12.615
7.	Jammu and Kashmir	8.010	1.715	9.725	5.498	1.561	7.059
8.	Karnataka	42.926	11.874	54.800	27.698	8.198	35.896
9.	Kerala	3.674	0.864	4.538	2.631	0.585	3.216
10.	Madhya Pradesh	61.658	19.074	80.732	41.185	12.919	54.104
11.	Maharashtra	88.298	19.688	107.986	57.052	13.639	70.691
12.	Nagaland	0.301	0.047	0.348	0.204	0.030	0.234
13.	Orissa	45.027	6.471	51.498	30.037	4.344	34.381
14.	Punjab	24.755	26.435	51.190	16.417	19.510	35.927
15.	Rajasthan	55.876	22.020	77.896	37.692	15.623	53.315
16.	Tamil Nadu	56.152	13.875	70.027	35.364	9.330	44.694
17.	Uttar Pradesh	128.252	50.780	179.032	80.108	34.575	114.683
18.	West Bengal	41.969	3.718	45.687	27.905	2.454	30.359
19.	Chandigarh	0.028	0.015	0.043	0.020	0.061	0.081
20.	Andaman and Nicobar Islands	0.034	0.093	0.127	0.015	0.014	0.029
21.	Dadra, Nagar Haveli, Laccadive, Minicoy, Amindive Islands	0.063	0.007	0.070	0.031	0.005	0.036
22.	Delhi	0.404	0.968	1.372	0.285	0.651	0.936
23.	Goa, Daman, Diu	0.766	0.241	0.007	0.481	0.157	0.638
24.	Manipur	1.045	0.240	1.285	0.654	0.164	0.818
25.	Lakshadweep	0.006	—	0.006	0.001	—	0.001
26.	Meghalaya	1.568	0.211	1.779	0.991	0.153	1.144
27.	Mizoram	0.079	0.011	0.090	0.053	0.007	0.060
28.	Pondicherry	0.419	0.057	0.476	0.275	0.044	0.319
29.	Tripura	1.800	0.095	1.895	1.111	0.066	1.177
Total:		744.565	258.022	1002.587	480.148	178.753	658.901

ORGANIC MANURES

of wet dung from cattle amounted to 744.565 million tonnes and that from buffaloes amounted to 258.022 million tonnes. Among cattle the percentage production of dung by different age-groups is as follows : young stock up to 3 years=11.85, adult females=30.89 and adult male=57.26. In the case of buffaloes, the percentage production of dung by different age-groups is as follows: young stock up to 3 years=16.51, adult females=64.43 and adult males = 19.06. Among cattle 60 per cent of the dung was produced by cattle from Uttar Pradesh, Maharashtra, Rajasthan, Madhya Pradesh and Tamil Nadu, whereas from the total buffalo dung nearly 73 per cent of the dung was produced by buffaloes from Uttar Pradesh, Andhra Pradesh, Rajasthan, Punjab, Bihar, Maharashtra and Madhya Pradesh. Out of the total annual dung production of 1002.587 million tonnes, Uttar Pradesh alone contributed to 18.9 per cent and 11.3 per cent by Maharashtra and 8.0 per cent by Andhra Pradesh. According to the IARS survey the contribution of Uttar Pradesh to the total dung production was 18.7 per cent (Goel *et al.*, 1973). The NCAER survey estimated the total annual bovine dung production at 1,335 million tonnes taking an average outturn of roughly 18 kg dung excretion per adult cattle, 23 kg dung per adult buffalo and 9 kg dung per young stock of cattle and buffalo.

The statewise annual outturn of urine from different groups of cattle and buffaloes in India is given in Table 12. The annual outturn of urine from cattle amounted to 480.148 million tonnes, whereas from buffaloes it amounted to 178.753 million tonnes. Among cattle the percentage distribution of urine by different age-groups is as follows : young stock=16.23, adult female=30.80 and adult male=52.97. In the case of buffaloes, the percentage production of urine for different age-groups of animal is as follows : young stock=22.42, adult female=60.24 and adult male=17.32. The total annual outturn of urine from cattle and buffaloes in India was 658.90 million tonnes and the overall dung excretion worked out to be about 1.552 times of urine excretion.

If the entire wet dung and urine excreted by the bovines is conserved for manurial purposes, its potentiality for soil nutrients has been worked out as under : 188.380 million tonnes organic matter, 2,822 million tonnes nitrogen, 1.069 million tonnes of phosphoric acid and 1,819 million tonnes of potassium oxide (Table 13). According to Garg *et al.* (1971) the annual production of dung and urine was estimated to be 1300 million tonnes and 370 million tonnes respectively and the potential total soil nutrients had been worked out as 4.89 million tonnes nitrogen, 1.37 million tonnes phosphoric acid and 3.85 million tonnes potassium oxide. According to IARS survey the available bovine dung that could be collected from households was 344.5 million tonnes and its manurial potential had been worked out as

AVAILABLE POTENTIAL OF ORGANIC MATERIALS AND PLANT NUTRIENTS

1.206 million tonnes nitrogen, 0.517 million tonnes phosphoric acid and 0.689 million tonnes potash (Goel *et al.*, 1973). They reported that nearly 29 per cent of the dung collected in households are burnt as fuel cakes, 69 per cent used for making manure and 2 per cent used for other purposes. However, the present report gives a realistic estimate as to the possible excretion of total dung and urine from the bovines in India.

Other Livestock and Human Excreta. According to Livestock Census 1972, India has a population of 108.419 million sheep and goats, 6.456 million pigs, 136.768 million poultry and 3.301 million other livestock including 0.966 million horses and ponies, 1.126 million camels, and 1.209 million other livestock. The present human population is 625.8 million. The annual excretion of dung and urine by different livestock and human beings is given in Table 14. The annual excretion of bovine dung and urine comprises 82.71 per cent of the total excretion by all other livestock and human beings. The sheep and goat excreta comprised 12.228 million tonnes dung and 7.918 million tonnes urine/year. The pig excreta comprised 4.596 and 3.990 million tonnes of dung and urine respectively. The poultry excreta per annum was 3.395 million tonnes. The excreta from other livestock comprised 6.024 and 4.095 million tonnes dung and urine per year respectively. The human excreta comprised 15.16 per cent of the total livestock and human excreta. The human beings excreted annually 30.380 million tonnes faeces and 274.100 million tonnes urine.

The annual manurial potential of bovine excreta alone is 2.822, 1.069 and 1.819 million tonnes N, P₂O₅ and K₂O, respectively (Table 13). The manurial potential of human excreta is 3.228, 0.776 and 0.715 million tonnes N,

TABLE 13. POTENTIALITY OF TOTAL ANNUAL DUNG AND URINE EXCRETION OF BOVINES FOR SOIL NUTRIENTS

Type of animal and manure	Annual excretion (Million tonnes)	N	P ₂ O ₅	K ₂ O	Organic matter
		(Million tonnes)			
Cattle					
Dung	744.565	1.117	0.745	0.372	139.872
Urine	480.148	0.960	0.048	0.960	—
Buffalo					
Dung	258.022	0.387	0.258	0.129	48.508
Urine	178.753	0.358	0.018	0.358	—
Total	—	2.822	1.069	1.819	188.380

P₂O₅ and K₂O, respectively (Table 15). The total annual manurial potential of all livestock and human excreta is 6.414, 1.973 and 2.662 million tonnes, N, P₂O₅ and K₂O, respectively.

ORGANIC MANURES

TABLE 14. ANNUAL EXCRETION OF DUNG AND URINE OF LIVESTOCK AND HUMAN BEINGS IN INDIA

S. No.	Animal type	Population (millions)	Daily excretion		Annual excretion (Million tonnes)		Total excretion (Million tonnes)	Per cent
			Dung (kg)	Urine (l)	Dung (kg)	Urine (l)		
1.	Cattle and buffalo	236.806	11.597	7.623	1002.587	658.901	1661.488	82.71
2.	Sheep and goats	108.419	0.300	0.200	12.228	7.918	20.146	1.00
3.	Pigs	6.456	2.000	2.000	4.596	3.990	5.586	0.43
4.	Poultry	136.768	0.068	—	3.395	—	3.395	0.20
5.	Other livestock	3.301	5.000	3.300	6.024	4.095	10,119	0.50
6.	Human beings	625.800	0.133	1.200	30.380	274.100	304.480	15.16
	Total				1059.210	949.004	2008.214	100

Slaughter-house wastes. There are about 3,000 slaughter-houses in the country handling annually nearly 40 million sheep and goats and 1.5 million buffaloes. About 12 million dead large animals are available annually. No systematic steps are taken towards organised collection of bones from dead animals and their utilisation.

Bonemeal. According to the report of the Directorate of Marketing and Inspection, it is estimated that about 4.5 lakh tonnes of bones are available every year in the country, out of which 1.36 lakh tonnes are collected and utilised by bone crushing mills.

Bonemeal is obtained as powder by crushing of bones, and it is used as fertilizer. Steamed bonemeal is obtained by treating the bones with steam under pressure and is used chiefly as phosphatic fertilizer. It also contains about 1 to 2 per cent nitrogen besides P_2O_5 (25 to 30%). Enormous amount of nitrogen and phosphate can be supplied by proper utilisation of bonemeal potential.

Bonemeal is considered useful for most of the soils and the best results are obtained in acidic soils. It is less effective in heavy clay and calcareous soils. It is more useful in soils well supplied with organic matter. Paddy, wheat and other cereals responded very well to application of bonemeal, particularly in acidic soils it can also be used for sugarcane, vegetables, fruits and legume crops.

TABLE 15. MANURIAL POTENTIAL OF LIVESTOCK AND HUMAN EXCRETA

Animal	Annual excretion (million tonnes)		Chemical composition								N (Million tonnes)	P ₂ O ₅	K ₂ O
			N		P ₂ O ₅		K ₂ O						
	Dung	Urine	Dung	Urine	Dung	Urine	Dung	Urine					
Cattle	744.565	480.148	0.15	0.20	0.1	0.01	0.05	0.20	2.077	0.793	1.332		
Buffalo	258.022	173.753	0.15	0.20	0.1	0.01	0.05	0.20	0.745	0.276	0.487		
Goat and Sheep	12.228	7.918	0.65	1.70	0.50	0.02	0.03	0.25	0.214	0.063	0.020		
Pigs	4.596	3.990	0.60	0.40	0.50	0.10	0.20	0.50	0.044	0.027	0.029		
Poultry	3.395	—	0.80	—	0.60	—	0.30	—	0.027	0.020	0.010		
Other livestock	6.024	4.095	0.50	1.20	0.30	—	0.30	1.00	0.079	0.018	0.069		
Human beings	30.380	274.100	1.60	1.00	1.20	0.15	0.55	0.20	3.228	0.776	0.715		
Total											6.414	1.973	2.662

ORGANIC MANURES

Bonemeal is likely to be contaminated with *Salmonella*, spores of *Bacillus anthracis* causing an anthrax disease in cattle and other pathogenic organisms. It can be made safe by sterilization.

Blood and Meat-meal. Blood-meal is used as nitrogenous fertilizer or as animal feed. The method for collection is faulty and therefore a large amount of blood is wasted. Availability of blood-meal is estimated about 55,000 tonnes and of this only one-third is utilized. It contains 10-12 per cent N, 1-2 per cent P_2O_5 and 1 per cent K_2O and its C/N ratio ranges between 3 and 4. It decomposes readily in soils. It can be used at any time during growth of crops. Solid slaughter-house wastes consist of waste meat, intestines, offal, etc. and has good manurial value. It is practically a waste at present. It is estimated that 0.12 lakh tonnes of meat-meal can be produced from dead animal wastes. If dried and ground, it will make a good fertilizer containing 8-10 per cent N and 3 per cent phosphoric acid with a C/N ratio between 2 and 3.

Hoof and Horn-meal. This is obtained by grinding hoofs and horns of animals after drying. It contains 10-15 per cent N, 1 per cent P_2O_5 and 2.5 per cent lime.

Leather Wastes. It is estimated that nearly 5,000 tonnes of leather wastes can be collected from slaughtered and fallen animals of total estimated to be 52 million heads for use of organic fertilizer. This remains unutilised at present.

Crop Residues and Aquatic Weeds

Crop Wastes. The potential of crop residues/straw of some of major cereal crops and pulses is given in Table 16. The straw yields have been worked out on the basis of average grain-straw ratio of different crops as indicated in the Table. It is clear from the table that there is huge quantity of renewable crop residues produced every year in the country. The five major crops alone yield approximately 141.2 million tonnes of straw and approximately 10 million tonnes of legumes residues. On average, cereal straw and residues on maturity contain about 0.5 per cent nitrogen, 0.6 per cent P_2O_5 and 1.5 per cent K_2O . The quantity of nutrients in legume residues is much higher than in cereal straw. The nutrient potential of cereal straw/residues is 0.7 million tonnes of nitrogen, 0.84 million tonnes of P_2O_5 and 2.1 million tonnes of K_2O . Even if 50 per cent of these crop residues are utilised as animal feed, the rest should be mobilised for recycling for their plant nutrient potential and other beneficial effect on soils and plants. The role of crop wastes in maintenance of soil organic matter under tropical and sub-tropical conditions needs no emphasis. Crop residues can be recycled either by composting, or by way of mulch or direct incorporation

AVAILABLE POTENTIAL OF ORGANIC MATERIALS AND PLANT NUTRIENTS

TABLE 16. POTENTIAL OF CROP RESIDUES/WASTES FOR RECYCLING
AS FERTILIZER/ANIMAL FEED

Crop	Average grain: straw ratio	Area (000 hectares)	Average yield/ha (kg)	Production in (000 tonnes)	Dry matter yield (000 tonnes)
Paddy	(1:1.02)	39688	1246	74474.2	89,369.04
Jowar	(1:1.5)	16101	592	9525.0	14,287.5
Wheat	(1:0.65)	20112	1409	28336.0	18,418.40
Bajra	(1:1.5)	11583	494	5726.0	8589.0
Maize	(1:1.5)	5996	1173	7036.0	19,554.0
Total Cereals	—	103,522.0	1040	107,698.0	—
Total Pulses	(1:0.75)	24,665.0	533	13135.0	9851.25

Paddy production figures have been estimated from rice production figures with the standard ratio of 2:3.

in the soil. Farmers should be advised by the Extension workers to conserve these manurial resources and suggest proper methods for utilisation of crop wastes.

Water Hyacinth. Water hyacinth (*Eichhornia crassipes*) is a free floating weed plant which grows luxuriantly in ponds, lakes and water reservoirs. It is estimated that total acreage under this weed is about 292,000 ha in Bengal, Bihar, Assam, Eastern U.P., Andhra Pradesh, Tamil Nadu, Orissa and Kerala. The adverse effects of such uncontrolled growth on agriculture, fisheries, transport and human health are obvious and the necessity for its collection and consequent disposal are needed.

Source of Mulch and Manure. Water hyacinth can be used as soil mulch, green manure and compost. Recently attempts have been made to use water hyacinth for biogas production without loss of plant nutrients. Water hyacinth is used as mulch in tea gardens during dry season for conservation of soil moisture and regulation of temperature. The plants can directly be ploughed in the soil and allowed to decompose for a month or so before sowing of a crop. However, the problem is that as plants are bulky, it is difficult to handle and transport to long distances.

Composting. The fresh plant contains 95.5 per cent moisture, 3.5 per cent organic matter, 1 per cent ash, 0.04 per cent nitrogen, 0.06 per cent phosphorus (P_2O_5) and 0.2 per cent potash (K_2O). This is a good source of potassium. It can be converted into compost without additional source of nitrogen. Addition of small amount of soil will accelerate the process of composting of water hyacinth. Since yields of water hyacinth are of

ORGANIC MANURES

the order of 250 tonnes per hectare per year, there is a potential for producing 3 million tonnes of compost annually in the country which will provide on dry basis about 20.5 kg N, 11.0 kg P_2O_5 and 25.0 kg K_2O per tonne. Water hyacinth compost is good for crops like rice, potato, maize, jute and vegetables. The recommended doses of compost for rice, maize and jute is 20, 5 and 7.5 tonnes per hectare, respectively.

Forest-litter Manure. It is estimated that about 15 million tonnes of compost can be obtained from forest-litter annually without in any way adversely affecting the natural regeneration of the forests. If a portion of the surface litter is removed in a regular manner, the manurial value of forest-litter is as good as farm compost. Fifteen million tonnes of forest litter manure may contain 0.075, 0.03 and 0.075 million tonnes of N, P_2O_5 and K_2O , respectively. At present, however, considerable amount of leaf litter is burnt and huge quantities of plant nutrients allowed to go waste.

Green Manuring. Legume plants are grown for fixing atmospheric nitrogen through *Rhizobium* symbiosis and plants after 8 weeks of growth are incorporated in soil to improve its fertility for raising another crop. Sunn-hemp, *dhaincha*, clusterbeans, *senji*, cowpea, *moong*, *urid*, fodder legumes, etc. are used as green manuring crops. *Dhaincha* and sunnhemp are more popular. Green manuring is confined to certain areas and in extensive agriculture. This practice has not extended in recent years. There are certain other practical difficulties such as lack of water supply for growth of green manure crops which are ascribed to its non-acceptability by the farmers.

Joffe (1955) indicated that the following single crop was only benefited due to green manuring and the favourable effect was not due to its contribution towards the improvement of organic matter and nitrogen content of soil. It was reported that the decomposition of legume residues was much faster as compared to farmyard manure and cereal residues and did not improve organic matter status of soils (Gaur *et al.*, 1970, 1971, 1973). Singh (1965) also indicated that 'legume effect' was more important as his experiments showed that increase in yields was not due to organic matter or nitrogen additions by green manure. His experiments also showed that berseem, *senji* and pea left through their root and stubble 89.4, 53.1 and 20.7 kg nitrogen per hectare. Although the practice of green manuring cannot be followed in intensive agriculture on a large scale, but certainly a fodder or grain legume can be included in multiple cropping sequence. Crop rotation involving sugarcane, cotton and *arhar* (pigeonpea) is ideal. Moreover, growing of legumes can save a certain amount of expensive nitrogenous fertilizers by improving the nitrogen status of soils. However, green manuring practices which do not interfere with the production of main crops should be popularised.

AVAILABLE POTENTIAL OF ORGANIC MATERIALS AND PLANT NUTRIENTS

TABLE 17. AVAILABLE POTENTIAL AND PRODUCTION OF ORGANIC MANURES THROUGH LOCAL MANURIAL RESOURCES

Manurial resources	Potential Qty	Achievements during different years (Million tonnes)									
		1950-51	1955-56	1960-61	1965-66	1973-74	1974-75	1975-76	1976-77	1977-78	1978-79
1. Rural Compost (million tonnes)	600.00	1.40	—	66.00	119.60	150.81	167.70	184.78	195.52	310.00	350.00
2. Green Manure (million hectares)	30.00	—	—	4.25	8.04	3.71	4.48	5.69	6.00	6.00	6.00
3. Urban Compost (million tonnes)	15.00	1.40	2.12	2.85	3.50	4.27	4.42	4.80	5.30	5.80	6.50
4. Sewage/sullage	800 m.g.d.*	—	—	—	12,267 (Area under irrigation in hectares)	24,000	24,000	26,208	30,000	35,000	40,000

* m.g.d. — million gallons/day

ORGANIC MANURES

Green-leaf Manuring. Green leaves from trees, viz. *Thespesia populnea*, *Cassia auriculata*, *Pongamia glabra*, *Melia azadirachta*, *Calotropis gigantea*, *Adhatoda vasica*, etc. are collected and used for green manuring in southern parts of India. Weeds, e.g., *Croton sparsifolius*, *Lucas aspera*, *Stachytarpheta indica* are also utilised for green-leaf manuring.

Some wild legume plants, viz. *Gliricidia meculata*, *Pongamia glabra*, *Calotropis gigantea*, *Tephrosia purpurea*, *Ipomoea carnea*, *Cassia tora*, *Sesbania* spp., *Indigofera teysmann*, *Tephrosia candida* can be grown on bunds and wastelands for utilising their vegetative parts for green-leaf manuring. A programme for raising wild legumes on bunds and wastelands may be developed for increasing its scope for its adoption.

Rural and Urban Wastes

Rural and Urban Solid Wastes. The potential availability of rural and town compost is estimated to be 600 million and 15 million tonnes respectively (Table 17). However, with the present efforts only 310-350 million tonnes of compost is prepared in villages by traditional and improved methods of composting. The present level of production of town compost is only of order of 6.5 million tonnes. However, with the set up of mechanised plants, the potential estimate of city waste is of the order of 50 million tonnes per year.

Sewage and Sullage. At present about 36 million urban population is served by drainage system producing about 292,000 million gallons sewage per annum (Table 17). Out of this potential, about 91,250 million gallons are utilised on organised sewage farms. It is estimated that during 1978-79 about 4,000 ha of land would be under sewage irrigation. Sewage has important components—water, plant nutrients and organic matter which are badly required in Indian agriculture. There is a scope for further expansion of sewage farming programmes now, and in future more cities will be provided with drainage systems.

Besides the necessity of sewage farming from point of view of utilization of the resources, it is also an effective method to avoid pollution. Unrestricted discharge of city liquid wastes in rivers and streams and on land results in pollution of environment and is a public health hazard.

There are two hundred and twenty sewage farms located in different parts of the country, about 102 such farms are located in six states, viz. Punjab, Uttar Pradesh, Tamil Nadu, Haryana, Gujarat, and Madhya Pradesh. The present utilization of waste waters is only about 31 per cent of the total potential. The average NPK content of an Indian city sewage is 50 ppm N, 15 ppm P_2O_5 and 30 ppm K_2O . Sewage sludge could form an important component of composting.

Waste stabilisation ponds have been recognised as effective and economical units for treatment of domestic sewage as well as industrial wastes. It is essentially a microbiological process involving simultaneous activity of bacteria and algae in presence of light, atmospheric oxygen and nutrients in waste waters. Effluents from stabilisation ponds contain algal cells and other nutrients. In addition to oxygenation due to photosynthetic activity, cellular algae is a good source of feed for the growth of edible variety of fish. The effluents from such treatment contain appreciable quantities of organic substances, nitrogen, phosphorus, potassium, etc. In oxidation ponds a part of these nutrients is removed from solution and concentrated in algal cells. The treated sewage effluent is safe and will not cause environmental pollution. The raw sewage contains 60-70 ppm N, 20-25 ppm total P_2O_5 and 40-45 ppm total K_2O and the secondary treated sewage contains 15-20 ppm N, 15-20 ppm total P_2O_5 and 35-40 ppm total K_2O .

Substantial volume of treated or partly treated sewage is usually being led into natural water streams. Thus the nutrients in waste water are not being effectively utilised. The total nutrients from urban and rural communities is substantial which should be recycled.

Agro-industrial Wastes

Agro-industries are based not only on crops, such as rice, sugarcane, jute, tea, coffee, fruits and vegetables but also based on forest products (non-edible oilseeds, wood, lac, etc.), marine products (prawns, fish, frogs and seaweeds) and slaughterhouse wastes and dead animals. Agro-industries wastes are available in substantial quantities at processing sites whereas animal wastes and crop residues are available at farms and in a scattered way. The characteristics and possible use as organic manures of some potential wastes are discussed below.

Oilseed Industry. Major oilseeds occupy an important position in the agricultural economy and are grown in area of about 16 million hectares (Anonymous, 1974). Groundnut is the most important crop followed by rape-mustard, *sesamum*, linseed and castor. Oilseed crops are essential part of human diet as well as provide important industrial raw material. Oilcakes obtained as byproducts are mostly used as cattle feed and manure (Kamalam *et al.*, 1960; Mahapatra, 1964). Groundnut hulls, obtained during the shelling of groundnut can be used as manure.

Non-edible Oilcakes. Oilcakes are the residues left after extraction of oil from oilseeds. About 0.3 million tonnes of non-edible cake is produced annually. Non-edible cakes such as *neem*, *karanj*, *mahua*, castor, etc. are used as organic fertilizer.

The manurial value of these cakes lies mainly in its nitrogen content

although it contains small quantities of P_2O_5 and K_2O . The nitrogen content varies from 3 to 9 per cent, depending on the nature of oilcake. The C/N ratio is low ranging between 3 and 15 for different types of oilcakes. Due to low C/N ratio its decomposition rate is faster than cereal and legume residues and other bulky organic manures. This nitrifies very quickly and about 60 to 80 per cent of its nitrogen is converted in available form within 2 to 3 months time. The nutrient content of some oilcakes is given in Chapter 11. Castor, groundnut, cottonseed, *mahua*, rape-seed, *neem*, *karanj* oilcakes are used as organic manures. *Mahua* cake is poor in nitrogen and takes longer time to nitrify. It is better to apply *mahua* cakes about 2 months in advance to soil before sowing of the crop. Oilcakes on economic grounds are not recommended for cereals like wheat or rice. Cakes are extensively applied for sugarcane crop and betel leaves. Castor cake is supposed to be good vermicide against white ants (termites). Recent investigations at I.A.R.I. have shown that due to application of oilcakes to soil the population of plant parasitic nematodes was decreased.

Rice Milling Industry. *Rice husk and rice bran.* Rice husk is the largest product of the rice milling industry comprising 20 to 25 per cent of paddy. Paddy yields about 5 to 7 per cent bran. The availability of rice husk is about 15 million tonnes annually. A typical paddy husk sample contains 42.6 per cent cellulose, 20.1 per cent lignin, 18.6 per cent pentosans and 18.7 per cent ash. The physical and chemical nature is unlike other crop residue wastes (McCall *et al.*, 1951; Beagle, 1971). It is a poor source of manure (Rajani and Patil, 1956) and its N content varies from 0.3 to 0.4 per cent, P_2O_5 0.2 to 0.3 per cent and potash 0.3 to 0.5 per cent. There is a problem of its disposal in certain areas. It is used as fuel and for improving physical conditions of saline and alkali soils. It can be used as bedding material for animals and in composting.

Rice bran yield is about 2.5 million tonnes annually. It has limited scope as fertilizer since this is exploited for production of rice bran oil.

Sugar Milling Industry. *Bagasse.* It is one of the most important byproducts of sugar industry. The fibre content of Indian sugarcane is 12 to 17 per cent and 33 per cent is bagasse. About 5.3 million tonnes of dry bagasse is annually produced. The bagasse produced in the country is almost entirely used as fuel in boilers of sugar factories. Recent investigations have shown that bagasse is a valuable material for production of pulp, paper, boards, etc. However, a portion of bagasse could be utilised as both for fuel and manure if it is processed through biogas plants. The nitrogen and P_2O_5 per cent of bagasse is approximately 0.25 per cent and 0.12 per cent and compost produced out of it will have a nitrogen of 1.4 per cent and 0.4 per cent of P_2O_5 . It is estimated that about 14 million tonnes of organic

manure per year can be produced from this byproduct.

A pilot plant is in operation at the National Sugar Institute, Kanpur which utilises bagasse and sugarcane trash for production of biogas. A composted fertilizer/manure is obtained within 40 to 45 days by this anaerobic process against longer period, normally required in compost pits. The approximate composition of each charge is 80 per cent cellulosic materials (bagasse), 12 per cent animal dung, 5 per cent bonemeal or superphosphate and 3 per cent calcium carbonate with moisture of about 70 per cent. The aerobic decomposition is allowed for 5 days by blowing compressed air resulting in rise of temperature to 60-80°C followed by anaerobic digestion for methane production. On dry basis, spent slurry contains 1.5-1.8 per cent N, 1.0-1.3 per cent P_2O_5 and 0.6-0.8 per cent K_2O . About 200 cu metre of biogas are obtained per tonne of organic matter contained in agricultural wastes. The biogas has a calorific value of 5,200 K cal per cu metre. The composition of the biogas produced is methane 55-60 per cent, carbon dioxide 30-35 per cent and hydrogen 5-10 per cent.

Press Mud. About 2 million tonnes of press mud is produced annually from the sugar factories. The bulk of the filter/cake is now used as manure in the fields, it contains about 1.25 per cent nitrogen and 2 per cent of P_2O_5 and 20 to 25 per cent organic matter. Compost prepared from press mud contains 1.4 per cent nitrogen and 1 to 1.5 per cent P_2O_5 . Since it is very high in lime (up to 45 per cent), its application is useful in acidic soils.

Forest Mill Wastes. Sawdust. The total of sawdust waste in the country from sawmill and plywood manufacture is estimated about 2.2 million tonnes. Sawmills alone account for 2.0 million tonnes of sawdust. It is a wide C/N ratio material (500:1) low in nitrogen (0.11%) and also low in phosphate (0.20%). It has limited scope to use as such as fertilizers, although some investigations have shown that it can be used as organic manure in tropical soils. Dried sawdust has good liquid absorbing capacity and can absorb 2-4 times more moisture than cereal straw/residues. Thus it can be used as a good absorbant for soaking urine in cattlesheds and as bedding materials for cattle which can be composted and converted in valuable organic manure. Its value as mulching material and for control of parasitic nematodes has also been recently reported.

Vegetable and Fruit Processing Industry. Vegetable and Fruit Wastes. A large quantity of wastes are obtained from peels, cores, pits, wine, stevia and other materials from vegetable and fruit processing plants. There is a wide scope for utilisation of these wastes as fertilizer. The total quantity available from this industry is more than 25,000 tonnes from mango, pineapple, citrus fruits, apples, green peas, tomato, etc. annually. It is estimated that about 10,000 tonnes of compost could be produced out of these wastes.

Cotton Mill. *Cotton wastes/Byproducts.* Cotton is an important commercial fibre crop of India. The present area under the crop is about 8 million hectares and production is about 6.5 million bales, valued at about rupees 800 crores. The main products of cottonseed are oilcake or meal, linters and hulls. Out of these, cotton oilcakes can be used as feed and fertilizer and the main wastes/byproducts arising from cotton are (1) cotton stalks, (2) cotton linters and hulls, (3) cotton leaves and other plant parts, (4) cotton dust. Rainfed cotton crop yields two-and-a-half tonnes of cotton stalks per hectare and under irrigated crop the yield of cotton stalks is about 5 tonnes/ha. Total production of cotton stalks on all-India basis is 12.0 million tonnes which are generally used for fuel purposes or burnt in the field for disposal. The necessary technology for converting it into manure should be developed.

Cotton Dust. Cotton textile mills mainly in their blowing rooms produce a large quantity of this waste, textile mills in India are expected to produce 30,000 to 33,000 tonnes of this waste per year.

The chemical analysis of the cotton dust in per cent is given below :

Moisture 8.0, organic matter 70.0, carbon 41.0, nitrogen 1.4, P_2O_5 0.6, K_2O 1.2 and pH 6.2. This material is ideally suited for composting and application to soils. The waste has plant nutrients (NPK) in greater proportion than routine city refuse. Its C/N ratio is ideal for composting. Studies carried out at CPHRE, Nagpur have shown that moisture content of 50-60% with a few turnings, a good quality compost can be prepared within 20 days. One tonne of raw material is estimated to give 0.6 to 0.7 tonne of finished compost. The cost of production works out to be only Rs 6 per tonne.

Tea Industry. During the course of tea production, processing and storage, about 10 million kg of tea waste becomes available in the form of fluffs, stalks and sweepings. It is an important raw material for extraction of caffeine. The decaffeinated tea wastes can be used as a manure or an animal feed. Spent tea waste has 0.28 to 3.5 per cent N, 0.4 per cent P_2O_5 and 1.5 per cent K_2O with C/N ratio of 9 to 11.

Tobacco Wastes and Tobacco Seed-cake. It is estimated that out of a total of about 62,000 tonnes of such waste available annually, nearly 41,000 tonnes are used for manurial purposes. The tobacco wastes used for manuring contain 0.5 to 1.0 per cent N, 0.8 per cent P_2O_5 and 0.8 per cent K_2O . About 10,000 tonnes of tobacco seed-cake is also available for manurial purposes and it contains 4 to 4.5 per cent N, 7 to 15 per cent P_2O_5 and 5 to 5.5 per cent K_2O .

Jute Sticks. The total quantity of jute sticks produced in India is about 2.5 million tonnes. It is generally used for thatching, hedging and for fuel purposes. Cellulose content of jute stick is quite high as compared to

bagasse, rice and wheat straw. It may be utilised in biogas after pre-treatment or by chopping it to smaller particle size.

Fisheries and Marine Industry

Seafood canning industry is an important industry in almost all the maritime states of the country. The wastes arise mainly during processing due to low market value of non-edible varieties, etc. Prawn shell and head, trash fish and frog legs are the main byproducts available in this country. A small quantity of prawn waste is used either as manure or for supplementing cattle and poultry feeds. Trash fish which constitute 15 to 30 per cent of the total marine catches are generally not preferred for table purpose because of their small size, bony nature and poor taste. These are converted into fish-meal and fish-manure.

In frog industry (Rao and Kamasastri, 1963) only the hind legs of certain frogs are processed while the head and the rest of the body which constitute about 65 per cent of the total weight are generally discarded.

Fish-meal processed by drying non-edible fish or waste from fish industry is a well-recognised balanced organic manure containing significant amount of nitrogen and phosphorus. Fish-meal is also produced by processing in steam digesters and then drying. The nitrogen content varies from 4 to 10 per cent, phosphoric acid from 3 to 9 per cent and K_2O about 1 per cent. It has a C/N ratio of about 4 to 5. The use of fish-manure is restricted to coastal areas.

Marine Algae and Seaweeds. Marine algae and seaweeds form a good source of organic manures amounting to about 10,000 to 15,000 tonnes annually. Seaweed contains 1 to 2 per cent P_2O_5 and 2 to 7 per cent K_2O and a number of trace elements.

Tank Silt. It consists of a large proportion of finer soil particles of silt and clay and organic matter carried by run-off water from the surrounding soil to the tanks during heavy rains. Pond and harbour muds have long been in use as soil ameliorant. The amount of fertilizing constituents present in tank-silt is not high, 0.3 per cent N, 0.3 per cent P_2O_5 and 0.3 per cent K_2O . It is considered as active culture of microorganisms, particularly the nitrogen-fixing ones. The residual effect of tank and river-silt is well established. It has been estimated that millions of tonnes of tank and river silt are available for application on land but remain unexploited every year.

V. FUNDAMENTALS AND PREPARATION, PROCESSING AND PRESERVATION OF ORGANIC MANURES

PREPARATION OF ORGANIC MANURES

Raw Materials. Compost and farmyard manure are processed from agricultural organic wastes such as straw, leaves, paddy husk, groundnut husk, sugarcane trash, bagasse, cattle dung and urine and habitation wastes like city garbage, nightsoil, sewage and sullage and vegetable matter. The materials undergo intensive decomposition under thermophilic and mesophilic conditions in heaps or pits with adequate moisture and finally yield a brown to dark coloured humified material in four to six months which is more stable in form, valuable for replenishments of plant nutrients, maintenance of soil organic matter and in improving the physical and microbiological conditions of the soil.

PRINCIPLES OF COMPOSTING

Action of Micro-organisms. The biodegradation process is carried out by different groups of heterotrophic micro-organisms, bacteria, fungi actinomycetes and protozoa. The role of cellulolytic and lignolytic micro-organisms in decomposition of crop wastes and residues is of prime importance. Micro-organisms involved in the process derive their energy and carbon requirements from the decomposition of carbonaceous materials and for every 10 parts of carbon, 1 part of nitrogen is required for building up of their cell protoplasm. Fungi are more efficient in carbon assimilation than bacteria and actinomycetes. Thus carbon dioxide evolution is comparatively less when fungi are more active in biodegradation than bacterial.

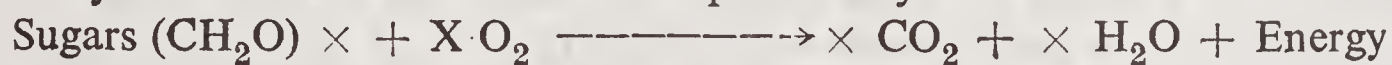
When organic materials are broken down in presence of oxygen, the process is called as aerobic decomposition. Under aerobic conditions, living organisms which utilise oxygen, decompose organic matter and assimilate some of the carbon, nitrogen, phosphorus, sulphur and other nutrients for synthesis of their cell protoplasm. Heterotrophs derive energy from the decomposition of organic matter, resulting on production of carbon dioxide, humic substances and release of available plant nutrients. Carbon serves both as energy source and is also required for cell protoplasm, greater amount of carbon is assimilated than nitrogen. Generally about two-thirds of the carbon is respired/evolved as CO_2 and the remaining one-third is combined with nitrogen in the living cells.

Aerobic decomposition of organic materials is most common in nature and generally occurs in arable soils and in forest soil surfaces where animal

PREPARATION, PROCESSING AND PRESERVATION

droppings and organic residues are stabilised into humus, with involvement of different groups of microflora. In the aerobic process, there are no nuisance problems such as foul odour associated with it as is produced under anaerobic conditions due to intermediate compounds.

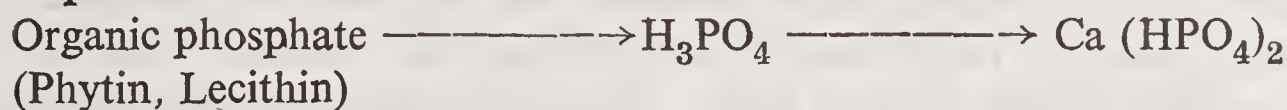
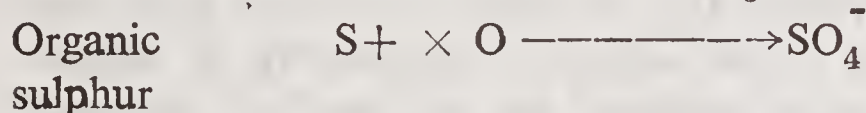
A great deal of exothermic energy is released during the oxidation of carbon to carbon dioxide. Organic materials in compost heaps or piles under proper insulation generate substantial amount of heat which increases the temperature up to 65-70°C. However, if the temperature exceeds 65-70°C, the microbial activity is decreased due to thermal kill of the micro-organisms and the stabilization of organic matter is slowed down. Thermophilic organisms develop when the temperature exceeds above 45°C, and they thrive best in the temperature range of 45°-65°C. The major reactions likely to occur under aerobic decomposition system are as follows :



Celluloses

Hemicelluloses

Lignins



Anaerobic micro-organisms break down organic materials by a process of reduction in absence of oxygen. First a special group of acid producing bacteria, facultative heterotrophs degrade organic matter into fatty acids, aldehydes and alcohol, etc. Then a group of bacteria convert the intermediate products to methane, ammonia, carbon dioxide and hydrogen. Oxygen is also required for the anaerobic process but its source is chemical compounds and not free dissolved oxygen. Like aerobic process, the organisms use nitrogen, phosphorus and other nutrients in developing cell protoplasm. During this process the decomposition is not complete and there is less production of carbon dioxide and intermediates, like organic acid will occur in greater amounts. So is the case of nitrogen containing substances such as ammonia. Due to lesser microbial bio-mass production and carbon assimilation, there is greater production of methane. This type of fermentation takes place in gober-gas plants, waste stabilisation ponds, in marshy soils, in buried organic materials devoid of oxygen or with low oxidation-reduction potential. Intensive reduction of organic matter is also known as a putrefactive process accompanied by foul odours of hydrogen sulphide and of reduced sulphur containing organic compounds such as mercaptans.

ORGANIC MANURES

As compared to aerobic process where the release of energy is much greater (484-674 K Cal/glucose molecule) only about 26 K Cal of energy per gram molecule of glucose are released. The energy of carbon is in the methane gas and the resultant energy from gober-gas plants in India is utilised for cooking purpose and can also be used in running engines. The biochemical reactions that occur in anaerobic decomposition of wastes are as follows:



Factors in Process of Composting. The most important factors in decomposition of organic wastes are as follows :

(i) carbon-nitrogen ratio, (ii) blending or proportioning of wastes, (iii) moisture and aeration, (iv) temperature, (v) reaction, (vi) microorganisms involved, (vii) use of inoculants, (viii) calcium phosphate, and (ix) destruction of pathogenic organisms.

C:N Ratio. The carbon-nitrogen ratio of organic materials is the most important aspect of composting. The process of conversion of organic materials into manure is chiefly microbiological and is, therefore, influenced by the proportions of carbonaceous and nitrogenous materials that are present in organic wastes to start with. Microorganisms need carbon for growth and nitrogen for protein synthesis. It was found that a C:N ratio of 30 of raw materials could be most desirable for efficient composting. The C:N ratio between 26 to 40 as reported by many workers, provide for rapid and efficient composting. If the organic material is poor in nitrogen or in other words, carbon nitrogen ratio is wide, biological activity diminishes and several successions/cycles of organisms may be required to degrade carbonaceous materials. Immobilised nitrogen is recycled on the death of some of the organisms. Thus the limited nitrogen is recycled by reducing the carbon content of the organic wastes. At low C:N ratio, ammonia is formed which under favourable conditions can be further oxidised to nitrite and nitrate. Other nutrients, like phosphorus, potassium, sulphur and micronutrients are also essential for microbial growth.

Lower C:N ratios under unfavourable conditions cause increasing loss of ammonia and higher values may prolong the period of composting. High C:N ratios are generally caused by organic materials poor in nitrogen such as cereal residues of wheat, paddy, *jowar*, *bajra*, maize, sugarcane trash, stalks of cotton, jute and sawdust. Farm and urban wastes have been found

PREPARATION, PROCESSING AND PRESERVATION

to vary widely in C:N ratio ranging between 30 and 80. As the stock of available nitrogen gets exhausted, the activity of nitrogen fixing micro-organisms predominates and thus there is a gain of nitrogen fixed from the atmosphere. With a C:N ratio of raw materials less than 30:1, the proportion of nitrogen is in excess of the requirements of micro-organisms. Although the process of decomposition goes on uninterrupted the unassimilable nitrogen is lost in the form of ammonia gas.

Similarly, 20 to 40 per cent nitrogen is lost in the form of ammonia during preparation of organic manure from cattle-dung and night-soil. This implies that a thorough mixing of these fractions with the carbonaceous wastes cannot be attained in practice and there are always pockets of concentration of nitrogenous materials which cause an imbalance in the decomposition process and loss of nitrogen. It is obvious that simple nitrogenous compounds are more susceptible to loss which are easily decomposed by micro-organisms and these compounds are of high utility to plants. Control of the loss and retention of this important plant nutrient in the final manure would be of practical value in obtaining a better quality manure.

The time of composting can be reduced by adding a nitrogen source of organic materials such as activated sewage sludge or by blending with organic residues richer in nitrogen such as legume residues and aquatic weeds (water hyacinth), slaughter-house wastes, green leaves, wastes of sugar, and wastes of antibiotic, yeast and paper industries.

Shredding and Blending. Composting process can be accelerated if raw materials are shredded into smaller pieces or ground since the material becomes more susceptible to bacterial attack due to exposure of greater surface area. The most desirable particle size for composting is less than 5 cm although larger sizes can be composted satisfactorily. However, the advantages of shredding may be uneconomical while composting on farms and in villages or by individual farmers.

The C/N ratio and moisture percentage are two important parameters which should be considered while mixing or blending different types of organic wastes for composting. There may not be any need of blending if the C/N ratio of organic materials is between 25 to 50, although 30 to 40 may be a good range. Substances poor in nitrogen such as sawdust, paper, straw, etc. can be mixed with comparatively nitrogen rich materials, e.g. legume residues, water hyacinth, slaughter-house wastes, fish scrap, night-soil, sewage sludge and biogas spent slurry to obtain a near optimum C/N ratio between 30 to 40. Similarly materials too dry and too moist can be blended together to obtain a desirable moisture level to avoid anaerobic conditions leading to bad odour.

ORGANIC MANURES

Soil at 5 to 10 per cent is also sometimes added to compost to reduce the moisture content and to absorb ammonia in low C/N ratio materials. The dry soil may be added if sufficient dry materials are not available. Soils may be added to high C/N ratio organic matter to buffer acid conditions and to act as a diluent for retarding anaerobic process. It can also be used for improving the appearance of finished compost to give it more granular structure.

Moisture. If the amount of moisture in the compost pile is below 40 per cent (W/W), decomposition will be aerobic but slow. Aerobic decomposition can go on at any moisture content between 30 and 100 per cent if adequate turnings are provided. During aerobic composting high moisture content should be avoided so that anaerobic conditions are not created. The optimum moisture level of 50 to 60 per cent may be quite satisfactory for aerobic composting. However, it may be in range of 40 to 80 per cent depending on the nature of organic material to be composted. At I.A.R.I., when composting fibrous materials containing straw were composted aerobically, 80 to 85 per cent moisture was maintained. If anaerobic composting is to be carried out, the maximum moisture content is not important. The moisture content between 80 to 90 per cent may be maintained.

Temperature. With the multiplication of microorganisms in the composting mass, the heat of exothermic biological reaction is retained due to sufficiently large mass and when the temperature rises above 40 °C, the mesophilic microorganisms are replaced by thermophilic. High temperatures are essential for destruction of pathogenic organisms and weed seeds. This generally occurs within 2 to 5 days of the start of the composting. The temperature in the middle of the pile goes up to 55° to 70 °C and after this it gradually cools to ambient temperature. Decomposition is fastest in the thermophilic stage. The optimum temperature based on oxidation of organic matter into carbon dioxide and water has been found by Willey and Pierce (1955) to be 60 °C. Schulz (1961) showed that a maximum temperature of 71 °C was optimal, but it was found that temperature should not exceed 70 °C for long because decomposition will be slowed down by a thermal kill of micro-organisms and only a few of the thermophilic organisms actively carry on decomposition above 70 °C. However, while composting high C/N ratio materials such as wheat and paddy straw, *jowar* stalk and *jamun* leaf fall, etc. of C/N ratio 48 to 50 in cubic metre pits, it was observed by Gaur *et al.* (1978, 1980) that temperature of the compost pile did not go beyond 52 °C. This indicated that extent of rise of temperature in compost will depend on the type material being composted and probably also on the size of the heap.

Reaction. The initial pH in compost heaps is generally slightly acidic around pH 6 as is found in the cell sap of most of the plants. The production of organic acids during the early stages of composting causes further acidification (pH 4.5-5.0) but as the temperature rises, the pH increases to slightly alkaline (pH 7.5-8.5) reaction (Anonymous, 1953).

Microbiology. The microbial population changes during aerobic composting, Chang and Hudson (1967) and Golueke (1954) have described a typical pattern. The fungi and acid producing bacteria appear during the initial mesophilic stage. As the temperature increases above 40°C, these are replaced by thermophilic bacteria, actinomycetes and fungi. Spore-forming bacteria develop at temperature above 70°C. Finally, mesophilic bacteria and fungi reappear as the temperature falls down.

Many aerobic mesophilic bacteria initially present in the composting material multiply and show increased activity. As the temperature is raised, their numbers decrease due to change in environment. A minimum is reached at 55° to 65°C during composting of grass cuttings and straw but their number increases again as temperature drops below 45° to 50°C.

The role of bacteria may be involved in raising the temperature of the compost for the development of thermophilic micro-organisms which colonise. Mesophilic bacteria which flourish during limited time, consume the most readily degradable carbohydrates. During the process compounds rich in nitrogen such as proteins, amino acids, blood-meal and peptones are bio-degraded especially by spore forming *Bacillus* spp. Actinomycetes degrade starch actively and also bring about large losses of water soluble fractions. Thermophilic bacteria do not appear to be important in degradation of cellulose and lignin but attack protein, lipids and hemicellulose fractions. Lipids are degraded to a great extent whereas degradation of celluloses and hemicelluloses is comparatively slow and intermediate. Lignin are the most resistant to decomposition and persist for longer period and tend to accumulate.

Actinomycetes (*Thermomonospora curvata*) may be important in cellulose decomposition (Golueke *et al.*, 1954). *T. curvata* was the most frequently occurring actinomycete in municipal and mushroom composts, because thermophilic actinomycetes can grow at higher temperatures than thermophilic fungi and they become dominant at the warmest stage.

Mesophilic fungi are present as the compost warms up moderately. These fungi are saprophytic sugar fungi which are quickly replaced by thermophilic fungi. The mesophilic fungi reappear in large numbers as the heap cools down below 40°C. Evidently they persist in outer layers during the thermophilic stage and reappear when the temperature drops. They can utilise cellulose and hemicellulose but not as efficiently as thermophilic fungi.

ORGANIC MANURES

TABLE 18. BACTERIA, ACTINOMYCETES AND FUNGI ISOLATED FROM COMPOST

BACTERIA	
Mesophilic	<i>Geotrichum candidum</i>
<i>Cellomonas folia</i> †	<i>Rhizopus nigricans</i>
<i>Chondrococcus exiguus</i>	<i>Trichoderma viride</i>
<i>Myxococcus virescens</i>	<i>T. (lignorum) harzianum</i>
<i>M. fulvus</i>	<i>Oospora variabilis</i>
<i>Thiobacillus thiooxidans</i>	<i>Mucor spinescens</i>
<i>T. denitrificans</i>	<i>M. abundans</i>
<i>Aerobacter</i> spp.	<i>M. variens</i>
<i>Proteus</i> spp.	<i>Cephalosporium acremonium</i>
<i>Pseudomonas</i> spp.	<i>Chaetomium globosum</i>
Thermophilic	<i>Glomerularia</i> sp.
<i>Bacillus stearothermophilis</i>	<i>Pullularia</i> (Aureobasidium)
	<i>Fusidium</i> spp.
ACTINOMYCETES	
Thermotolerant and Thermophilic	<i>Actinomucor corymbosus</i>
<i>Micromonospora vulgaris</i>	<i>Mucor jansseni</i>
<i>Nocardia brasiliensis</i>	<i>Talaromyces (Penicillium) variabile</i>
<i>Pseudonocardia thermophila</i>	<i>Helminthosporium sativum</i>
<i>Streptomyces rectus</i>	<i>Aspergillus fumigatus</i>
<i>S. thermofuscus</i>	
<i>S. thermoviolaceus</i>	Thermotolerant and Thermophilic
<i>S. thermophilus</i>	<i>Humicola insolens</i>
<i>S. thermovulgaris</i>	<i>H. griseus</i> var. <i>thermoideus</i>
<i>S. violaceoruber</i>	<i>H. lanuginosa</i> (<i>Thermomyces lanuginosus</i>)
<i>Thermomonospora curvata</i>	<i>Mucor pusillus</i>
<i>T. fusea</i>	<i>Chaetomium thermophile</i>
<i>T. glaucus</i>	<i>Absidia ramosa</i>
<i>Thermopolyspora polyspora</i>	<i>Talaromyces (Penicillium) duponti</i>
FUNGI	
Mesophilic	<i>T. emersonii</i>
<i>Fusarium culmorum</i>	<i>T. thermophilus</i>
<i>F. roseum</i>	<i>Sporotrichum thermophile</i>
<i>Stysanus stemonitis</i>	<i>S. chlorinum</i>
<i>Coprinus cinereus</i>	<i>C. t. 6</i> (<i>Mycelia sterilia</i>)
<i>C. megacephalus</i>	<i>Stilbella thermophila</i>
<i>C. lagopus</i>	<i>Malbranchea pulchella</i> var. <i>sulfurea</i>
<i>Clitopilus pinsitus</i>	(<i>Thermoidium sulfureum</i>)
<i>Aspergillus niger</i>	<i>Dactylomyces crustaceus</i>
<i>A. terreus</i>	(<i>Thermoascus durantidicus</i>)
	<i>Byssoschlamys</i> spp.
	<i>Torula thermophila</i>

Thermophilic fungi occur when the temperature ranges between 40°C and 60°C. Like mesophilic fungi, they survive in the periphery of the heap when the temperature exceeds this range. The bacteria, fungi and actinomycetes isolated and reported from compost are presented in Table 18 (Poincelot, 1972).

Inoculants and other Preparations to Compost. If C/N ratio is too wide, adding nitrogen can hasten composting by lowering the ratio. Microbial inoculations may also be beneficial in a compost heap poor in micro-organisms for speeding up decomposition of materials rich in cellulose and lignin.

PREPARATION, PROCESSING AND PRESERVATION

It has been observed in sawdust compost that inoculation with spores of cellulolytic fungus, *Coprinus ephemerus* and addition of nitrogen, phosphorus and potash shortened composting of sawdust from usual 1-2 years to 3 months and produced a compost that did not immobilise nitrogen as compared to fresh sawdust (Davey, 1953; Wilde, 1958).

Japanese patents for additives to accelerate decomposition of wood products have been reported recently. The addition of nitrohumic acid (humus or complex natural ligno-protein treated with nitric acid) to bark wastes and chicken manure (1:7:100) reduced the decomposition time from 180 days to 60 days (Dai *et al.*, 1972; Sailo *et al.*, 1972). Decomposition of wood pulp was improved by urea and crude acetic acid distilled from wood. The recent work done in India on microbial inoculants for accelerating the compost-making has been discussed separately in this chapter.

Calcium Phosphates. Several investigators have reported that calcium phosphate increases the rate of decomposition and nitrogen conservation (Chekalov, 1955; Arzamasova and Kuzimenkova, 1962) but more than 2 per cent inhibited the decomposition rate (Gaur *et al.*, 1980). Chang (1939) found increased rate of decomposition occurring mainly in cellulose and hemicellulose fractions. The number of cellulolytic microorganisms increased with the addition of phosphate and conserved nitrogen by decreasing the number of denitrifying bacteria (Karokin, 1962; Tepla, 1959). Although N fixation may be increased by adding calcium phosphate (Berezova *et al.*, 1955), there is generally sufficient phosphate in the organic wastes for meeting the requirements of microorganisms which need about 5 to 20 per cent only as much P as N. However, our experiments have shown that application of rockphosphate is important for nitrogen conservation and enrichment of organic manures, while composting wide C/N ratio organic materials (paddy, jowar straw, jamun leaves). Gaur *et al.* (1978, 1980) recorded that *Azotobacter* numbers in compost were greater in presence of added rockphosphate.

Gaur *et al.* (1980) reported that addition of rockphosphate at 1.0 per cent (W/W) increased the decomposition of paddy straw by cellulolytic fungi (*Aspergillus* spp. supplemented with urea nitrogen) (Table 19). The carbon content was decreased by 17.2 per cent and nitrogen augmented by 31.4 per cent. As a result C/N ratio of 23.1 was obtained within 8 weeks as compared to 37.7 in the control. Increased amounts of rockphosphate (2 and 3 per cent) showed slight reduction in decomposition intensity. Mathur and Debnath (1980) from Ranchi Agricultural College reported that quality of compost prepared from mixture of paddy straw, grass and water hyacinth was improved when rockphosphate was applied to it with and without pyrite. The chemical composition of the compost is given

ORGANIC MANURES

in Table 20. The results showed that low dose of rock phosphate (5 per cent) increased the nitrogen content by 30 per cent of the compost over the control. The enrichment of compost with rock phosphate besides increasing the phosphorus content, increased the concentration of calcium and micronutrients particularly of iron, manganese and zinc. Beneficial effect of addition of rock phosphate at an optimum rate during the initial stage of compost making has been reported at I.A.R.I. and I.C.A.R. Co-ordinated Project on "Microbial Decomposition and Recycling of Organic Wastes."

TABLE 19. EFFECT OF ROCKPHOSPHATE ON THE DECOMPOSITION OF PADDY STRAW BY *Aspergillus* SPP.

Treatments	% loss in weight (2 months)	Organic matter %	Carbon %	Total N%	C/N ratio
Urea (0.5% w/w) control	45.2	75.35	43.71	1.190	37.73
Urea + Rock phosphate (1.0% w/w)	55.0	62.36	36.17 (—17.2)	1.564 (31.4)	23.12
Urea + Rock phosphate (2.0% w/w)	52.9	62.64	36.33 (—16.9)	1.326 (11.24)	27.40
Urea + Rock phosphate (3.0% w/w)	52.8	64.60	37.47 (—14.3)	1.275 (7.1)	29.39

Figures in parentheses show per cent loss or gain

TABLE 20. CHEMICAL CHARACTERISTICS OF COMPOST PREPARED WITH ROCK PHOSPHATE

Components	T ₁	T ₂	T ₃
Total Ca (%)	1.85	2.27	1.92
Total Mg (%)	0.37	0.51	0.38
Total Na (%)	0.06	0.19	0.09
Total K (%)	0.92	0.81	0.83
Fe (ppm)	5,080	12,720	28,200
Mn (ppm)	180	520	540
Zn (ppm)	60	95	80
Cu (ppm)	10	24	44
pH	4.40	5.55	5.80
Organic Carbon (%)	14.64	18.06	12.83
Total Nitrogen (%)	0.61	0.79	0.58
C/N ratio	24.00	22.80	22.10

T₁ = 650 kg raw material (P_o)

T₂ = 650 kg raw material + 32.5 kg Mussoorie rock phosphate (MRP)

T₃ = 650 kg raw material + 32.5 kg (MRP) + 32.5 kg Amjhore Pyrite

PREPARATION, PROCESSING AND PRESERVATION

Destruction of pathogens and parasites. The destruction of pathogens and parasites of animals and humans is an important aspect and a problem when compost is prepared from materials containing sewage sludge and nightsoil. Aerobic composting at high temperatures is effective in killing pathogens. Gotaas (1956) recommended 60°C for "Thermal Kill" of common pathogens listed in the Table 21.

TABLE 21. TEMPERATURE AND TIME OF EXPOSURE REQUIRED FOR DESTRUCTION OF SOME COMMON PATHOGENS AND PARASITES

Organism	Observations
<i>Salmonella typhosa</i>	No growth beyond 46°C; death within 30 minutes at 55°-60°C and within 20 minutes at 60°C; destroyed in a short time in compost environment
<i>Salmonella</i> spp.	Death within 1 hour at 55°C and within 15-20 minutes at 60°C
<i>Shigella</i> spp.	Death within 1 hour at 55°C
<i>Escherichia coli</i>	Most die within 1 hour at 55°C and within 15-20 minutes at 60°C
<i>Entamoeba histolytica</i> cysts	Death within a few minutes at 45°C and within a few seconds at 55°C
<i>Taenia saginata</i>	Death within a few minutes at 55°C
<i>Trichinella spiralis</i> larvae	Quickly killed at 55°C; instantly killed at 60°C
<i>Brucella abortus</i> or <i>Br. suis</i>	Death within 3 minutes at 62°-63°C and within 1 hour at 55°C
<i>Micrococcus pyogenes</i> var. <i>aureus</i>	Death within 10 minutes at 50°C
<i>Streptococcus pyogenes</i>	Death within 10 minutes at 54°C
<i>Mycobacterium tuberculosis</i> var. <i>hominis</i>	Death within 15-20 minutes at 66°C or after momentary heating at 67°C
<i>Corynebacterium diphtheriae</i>	Death within 45 minutes at 55°C
<i>Necator americanus</i>	Death within 50 minutes at 45°C
<i>Ascaris lumbricoides</i> eggs	Death in less than 1 hour at temperatures over 50°C

The extent and duration of high temperatures in compost heaps as well as antibiosis as a result of mixed population of microorganisms provide reasons to believe that pathogens and parasites are not able to survive the composting process. To achieve this at least 2 to 3 turnings of compost heap is suggested. Knoll (1959, 1961, 1963) found that 65°C for one day ensured elimination of *Salmonella* spp. Stranch (1964) reported the destruction of *S. enteritidis*, *Erysipelothrix*, *Rhusiopathiae* and the *Psittacosis* virus under similar conditions. *Bacillus anthracis* was destroyed only at temperature above 55°C for 3 weeks or longer at a moisture content of 40 per cent or more. He concluded that higher temperature may not be the only way to kill

ORGANIC MANURES

pathogens during composting but some are killed by competition with other microorganisms. Schraff (1940) and Scott (1953) found that resistant forms of parasites such as *Ascaris* eggs, cysts of *Entamoeba histolytica* and hookworm eggs were destroyed during aerobic composting. Scott (1952) found that at least 2 turns were necessary for the destruction of *Entamoeba histolytica* in 12 days and three turns were required to destroy the eggs of *A. lumbricoides* in 36 days. Anaerobic composting at the mesophilic temperature range does not effect satisfactory destruction of parasites in a relatively short time. Anaerobic composting when using sewage sludge or nightsoil should be preceded by aerobic composting at least for a week. The natural death of pathogens and parasites will occur in an anaerobic environment and the microbial antagonism will eventually eliminate them but this will generally take longer period of about six months.

Heaps versus Pits. When preparation of manure is carried out in over-ground heaps, the decomposition becomes mainly aerobic, with air freely accessible for microorganisms to carry out their activities. The rate of decomposition is accelerated if periodical turnings are given which also promotes physical disintegration of the raw materials. Owing to quick oxidation of organic matter, high temperatures (60°-70°C) develop, thereby killing weed seeds and pathogenic organisms. Loss of organic matter in this process often amounts to above 50 to 60 per cent and decomposition may continue even after the C/N ratio is reduced to the optimum. Loss of nitrogen from 20 to 50 per cent invariably takes place in this method.

Moisture content necessary for microbial activity is effected in the heap method, with losses occurring because of exposure to the atmosphere and the high temperatures that develop in the manure heap. In dry climate, this would affect the rate of decomposition and necessitate addition of extra water periodically. During the rainy season, on the other hand, there may be too much of water in the heap to slow down decomposition and even cause loss of nutrients and organic matter by leaching, unless manure preparation is carried out under sheds. This is not always feasible where large quantities of manure are required to be prepared.

Preparation of manure in pits has several advantages over method of preparation in heaps over ground although it involves some initial expenditure on digging and permanent occupation of land for this purpose. The decomposition is mainly anaerobic, except in the surface few inches and proceeds slowly. Losses of organic matter as well as nitrogen are consequently reduced, amounting to about 25 and 20 per cent respectively, enabling a larger quantity as well as good quality of the manure to be obtained. However, the process of composting can be accelerated by providing a few turnings at periodic intervals which will create aerobic conditions

PREPARATION, PROCESSING AND PRESERVATION

as well. The materials are protected against loss of moisture by evaporation as well as excess of water in the rainy season and physical loss of nutrients by leaching. High temperatures do not develop in this case owing to the anaerobic nature and the slow rate of decomposition. But weed seeds and pathogenic organisms are destroyed because of the toxic products of this type of decomposition. Little physical disintegration of material such as straw and refuse, however, takes place in this system but this is not necessary from scientific standards of assessment of quality of manure of which a final C/N ratio of less than 20:1 indicates its maturity and fitness for application to land. The manure may remain stored in pits until required without much loss due to very restricted decomposition after it is ready.

UTILISATION OF URINE FRACTION

The liquid excreta of animals contains nitrogen in the form of urea, phosphorus, potash and several other nutrients in water soluble form which are of high utility to plants. Stress has always been laid on proper collection of this fraction and its utilization by adding urine-soaked litters or urine-earth to the manure-pit. However, in the process of its microbial fermentation with carbonaceous materials, the original simple compounds of nitrogen are converted into complex microbial proteins or into ligno-proteins by chemical reaction. There is also considerable loss of nitrogen in the form of ammonia due to the ease of decomposition of urea by numerous microorganisms. An overall reduction in the manurial value of this fraction thus takes place when it is incorporated in manure heaps. The low C/N ratio of urine and the simple nature of its nitrogenous compounds suggests that its separate collection and direct utilisation as manure would be a more effective alternative if practical methods of collection and conservation of this liquid manure are evolved. Work on this aspect carried out at the Indian Agricultural Research Institute and National Dairy Research Institute showed that urine-soaked earth can be treated with superphosphate or gypsum to control the decomposition of nitrogen and then quickly dried to stop bacterial activity or urine-soaked ground paddy husk or sawdust can be composted along with dung with a good quality manure. The plant nutrient constituents thus remain conserved in their original form and the manure obtained is highly effective. Alternative materials like dry leaves, dry dung, etc. can be used in conjunction with soil in cattle-sheds to soak urine more effectively and processed as above. In *pucca* cattle-sheds where urine and cattle-shed washings are collected in cess pits, the liquid manure may be similarly treated with superphosphate or a mineral acid like hydrochloric acid and then soaked and dried in absorbing materials

ORGANIC MANURES

of the type mentioned.

Results obtained at the Indian Agricultural Research Institute have shown that the method can be effectively extended and applied to the collection and utilisation of large quantities of human urine which has not been exploited so far. A simple design of urinals evolved by the Institute (I.A.R.I.) enables urine to be collected in absorbing materials contained in a drum or a pit dug for the purpose. The decomposition of urine is controlled by acidulating the material with superphosphate or hydrochloric acid. The material can be repeatedly soaked and dried to obtain concentrated manures. Dehydrated human urine manures have been found to be highly effective in stimulating growth and yield of crops. The proposition of separate collection and utilisation of cattle and human urine in the above manner offers a new, yet unexplored field for efficient utilisation of an inexhaustible and rich source of manure available in the country.

EFFECT OF HUMAN URINE DEHYDRATED IN DIFFERENT MATERIALS ON WHEAT (MANURES APPLIED AT 112 KG N/HA)

Treatment	Yield in g from 30 plants.		
	Grain	Straw	Total
No manure	11.5	23.8	35.3
Urine in soil	26.6	33.9	60.5
Urine in saw-dust	27.4	37.5	64.9
Urine in charcoal-dust	28.0	37.3	65.3
Ammonium sulphate	22.8	51.6	54.4
C.D.	5.7	4.8	7.6

PREPARATION OF FARMYARD MANURE

Organic waste materials that generally go in production of farmyard manure including dung, urine, soaked earth or litter, remnants of cattle food, ash and other household and kitchen wastes. The existing method of preparation by dumping the small daily collection in a heap or shallow pit leaves much to be desired and yields a low-quality manure.

Sectional filling. One of the effective methods of preparation of farmyard manure that has been found to yield superior quality manure is the process called 'Sectional Filling of Trenches', which includes all the advantages of carrying out of decomposition in pits and suits well to the conditions existing in this country of having to deal with a comparatively small daily

PREPARATION, PROCESSING AND PRESERVATION

collections. The method consists of digging suitable-sized trenches depending on the number of cattle as follows:

No. of cattle	Length (m)	Breadth (m)	Depth (m)
2 to 5	6.5	1.0	1.0
6 to 10	8.0	1.2	1.0
11 to 20	10.0	1.4	1.0
above 20	10.0	1.6	1.0

Filling of mixed wastes from the cattle-shed is recommended from one end of the trench in a section, one metre in length. A movable partition made from cotton stalks or such other material between two bamboo poles is used for making the section to be filled. The daily collection is dumped in this and covered with a thin layer of soil. This is continued until the section is filled to a level of about 50 cm above ground level. The top is then covered with earth and the partition is moved one metre further along the length to form the next section for filling as before. Leaves and other farm wastes like paddy and groundnut-husks, straw, etc. could be added to increase the quantity of manure if sufficient litter from the cattle-shed is not available. The manure is ready in about three months and contains about 2 per cent nitrogen on dry weight basis. The quantity of manure obtained per pair of animals amounts to 10 to 12 tonnes per year.

COMPOSTS

The principles of production of farmyard manure from cattle-shed wastes have been extended for the preparation of 'composts' in which a variety of carbonaceous and nitrogenous waste materials may be utilised. Thus, farm-wastes like straw, chaff, leaves, paddy and groundnut-husks, sugarcane-trash, bagasse and other agricultural as well as industrial and habitation wastes of all sorts like street-refuse, night-soil, slaughter-house wastes, sewage and sullage water, sludge, etc. can be pressed into service to yield manures.

In India, pioneering work in this field was carried out by Howard and Wad (1931) at Indore and Fowler at Bangalore, who standardized conditions for degradation of leaves, straw and town-refuse, utilizing dung and nightsoil as starters for promoting bacterial activity.

Indore Method of Composting.

In this method the waste materials are spread out and moistened with

dung or night-soil slurry. These are then built up into heaps, four to six metres in length, one metre in breadth and one metre in height. Under these conditions, the rate of decomposition is rapid and high temperatures develop quickly. The process is accelerated if turnings are given, whereby aeration and mixing of the materials and moistening at this stage, if necessary, cause more or less total disintegration, yielding a brown homogeneous manure in about three months. Under this aerobic process of decomposition losses of organic matter and nitrogen are heavy, amounting to 40 to 50 per cent of the initial. The manure resembles the traditional farm-yard manure in appearance and properties and it has been shown that decomposable organic materials of any type can thus be processed to supplement the supplies of manure. This method of manure preparation, however, involves considerable labour in building up the heap to proper shape and periodical turnings that are given and becomes expensive and impracticable where large quantities of materials have to be processed. However, the turnings of the mass are not necessary and decomposition can go on to the desired extent if adequate moisture level is maintained. The average composition of manure prepared by the Indore method has been found to be 0.8 per cent nitrogen, 0.3 per cent phosphoric acid and 1.5 per cent potash.

Fowler worked out the process of 'activated compost' in which fresh raw materials are incorporated in an already fermenting heap so that the established and large microbial population brings about quicker decomposition. The process is useful particularly where offensive materials like night-soil are to be quickly and effectively disposed of.

Compost from Habitation Wastes—Bangalore Process

Pioneering work in preparation of manure in pits has been carried out in India by Acharya (1939), particularly on the utilisation of town-refuse and night-soil. What is called the hot fermentation method of manure production or the Bangalore process has by now been adopted in many towns in India, solving effectively one of the most difficult problems of sanitary disposal of these offensive wastes and yielding a high quality organic compost manure in the bargain. The operative part of the process can be adapted to the prevailing system of collecting refuse and night-soil. The method carried out in practice is as follows :

The compost production depot is located just on the outskirts for convenient transport of street-refuse and night-soil to the pits. In large towns, there may be two or three such depots to serve different localities. The compost depot should accommodate about 200 trenches of dimension as under, which can take the dumpings for one year :

PREPARATION, PROCESSING AND PRESERVATION

Population (in '000)	Length (m)	Breadth (m)	Depth (m)
below 10	4.5	1.5	1.0
10 to 20	6.0	2.0	1.0
20 to 50	9.0	2.0	1.0
above 50	10.0	2.5	1.0

The trenches are dug in rows, with a space of 1 to 5 m between trenches. Roads of suitable width are provided between rows for the carts to approach and unload the materials inside the trenches. At first the refuse is dumped into the trench and spread out with rakes to make a layer of 15 cm. Night-soil is then discharged over this and, if necessary, spread out with long wooden spades in a layer of about 5 cm. This is then covered with a 15 cm layer of refuse. Night-soil and refuse thus follow in alternate layers until the pit is filled to 15 cm above ground level, with a final layer of refuse on the top. This may be dome-shaped and covered with a thin layer of soil. In some towns, night-soil comes mixed up with refuse in which case the material is simply dumped to fill the trenches. Sullage water, if collected in carts as in some towns, may also be emptied over the layers of refuse. In fact, the system provides a method of disposal of every kind of waste that the town may have, including slaughter-house, carcasses of animals, sewage, etc.

The decomposition of dumped materials in pits takes place largely in the absence of sufficient air except in the surface foot or so. This anaerobic decomposition is comparatively slow but markedly less wasteful. The difference in recovery of organic matter and nitrogen by this method as compared with the aerobic method in over-ground heaps is given below for manure prepared from town-refuse and night-soil.

PERCENTAGE RECOVERY

	Heap	Trench
Organic matter	53	78
Nitrogen	54	74

In this method, no high temperatures develop in the lower layers and since the material does not receive turnings, disintegration into a homogeneous mass of manure does not take place. Even so, the C/N ratio is reduced to less than 20:1 in about six months and the manure is then ready

for use. Deeper in the trenches, the material still possesses an unpleasant smell and it is desirable to dig it out and pile it up outside for some days before disposal.

In the absence of facilities for digging trenches, town-refuse and night-soil compost can be prepared in over ground heaps of one metre height, one metre width and any convenient length, with refuse and night-soil, placed in alternate layers, as in trenches and a final refuse layer on the top. Night-soil carts empty the material along the length of heap. No turnings need be given to the heaps and the material decomposes more quickly than in pits and can be used after three to four months.

The basic aspect of these processing treatments in manure production is that after the initial active decomposition and loss of excessive carbon has taken place, the proportion of nitrogenous night-soil and organic carbonaceous material is just proper and it can be used as manure. Often, the night-soil and refuse layers can be identified when the manure is dug out. The material gets mixed up only while it is being taken out, but because the mixture is in proper proportion, it is safe to apply as manure. Further decomposition is carried out in the soil itself and because of the presence of adequate nitrogen this causes no adverse effect and instead soon releases nitrogen for crops to assimilate.

In villages individual latrines are limited to only a few rich families, hence night-soil collection and its compost making is not popular. It can, therefore, be a great step in improving the existing insanitary conditions to provide suitable community or individual latrines, preferably Wardha-type trench latrines to villagers to utilise human-wastes. Before putting Wardha-type latrines in use, a 7.5 cm layer of refuse (grass, leaves, straw, weeds, trash, etc.) is spread at the bottom of the trench. A stock of refuse or dry earth is left to cover the faeces. After the material rises to a height below 15 cm of the top, the trench is sealed for decomposition and another trench put in use. Manure of good quality is ready in four to six months.

Preparation of Synthetic Compost

The basic principles underlying the microbiological process of conversion of organic wastes into manure have been extended for preparation of synthetic composts, using inorganic fertilizers as sources of nitrogen for decomposition of carbonaceous materials. It has been found that organic nitrogen in the form of dung, required by microorganisms, can be completely substituted by inorganic nitrogen compounds like ammonium sulphate and urea, which are utilised equally effectively for decomposition and well fermented manure, resembling farmyard manure, can thus be obtained. This opens up a vast field for utilisation of large quantities of various organic

waste materials where supplies of dung are either short of requirements or not available at all, as on mechanized farms. The basic principles of C/N ratio in manure preparation can be applied to add nitrogenous fertilizers in sufficient quantity to reduce the ratio to about 30-40 : 1 and then allow the material to be decomposed and disintegrated until the C/N ratio is reduced to 20 : 1. The adco process of preparation of synthetic compost worked out by Hutchinson and Richards is based on this principle.

This process of production of compost from organic wastes of wide C/N ratio is worked with fertilizers like ammonium sulphate or urea. They provide complete or partial nitrogen for microbial decomposition in place of natural materials like dung or night-soil which may not be available at all or may be in short supply. Nitrogen is added to make up a total of 1.2 per cent on dry weight basis of the material. Thus straw containing 0.4 per cent nitrogen requires an additional 0.8 per cent nitrogen, i.e. about 4 kg of ammonium sulphate per 100 kg of straw. For neutralizing acidity, which may develop in this system, the process includes addition of lime at the rate of 5 kg to the above material. The material to be composted is spread out in layer in a heap or pit and sufficiently moistened. This is sprinkled with the fertilizer solution and then with lime. Superphosphate may be added to fortify the phosphatic contents of the manure. The treatment is continued layer-wise until the heap or pit is filled to size and allowed to ferment. The manure becomes ready for application in about four to six months and resembles farmyard manure in its action on soil and plant growth.

Mechanical Compost Plants

Although the major quantities of compost (310-350 million tonnes) at present used in agriculture are prepared in villages either by traditional or improved methods (Indore or Bangalore methods), these methods cannot be suitably used for processing of large quantities of organic refuse of bigger cities.

The mechanised/semi-mechanised plants will serve two pertinent objectives — sanitary disposal of city refuse and production of organic manure. It is estimated that by 1979 nearly 50 million tonnes of municipal wastes will be generated annually in India (Gaur, 1978). Moreover, Indian city wastes contain about 50 to 80 per cent of compostable organic materials which can be processed conveniently in compost plants. During Sixth Five Year Plan, Ministry of Agriculture and Irrigation timely launched a programme to set up 35 composting plants in selected cities with a population of 3 lakhs and above. Five compost plants have already been set up one each at Ahmedabad, Baroda, Bangalore, Calcutta and Jaipur and the

remaining 30 plants are expected to be set up during Sixth Five Year Plan (1978-83). The intake capacity of these plants already set up is about 125 to 200 tonnes garbage per day and can produce 60 to 70 tonnes of finished compost per day if the plant runs in shifts.

The costs of production is rather high due to mechanisation of the processes and at some places the plants were running at under-utilised capacity due to non-availability of required quantities of garbage. The selling price of finished compost has been kept between Rs 50 to 80 per tonne depending upon the composting system adopted and plant capacity. The cost may be reduced by installation of plants with less mechanisation.

The compost prepared from city wastes is bulky and low in plant nutrients. It contains 0.5 to 0.6 per cent N, 0.6 per cent P_2O_5 and 0.5 per cent K_2O with a C/N ratio of 20:1 (Gaur, 1979). There is a need to enrich this manure in respect of nitrogen and phosphorus and reduce its bulkiness involving low-cost technology. The work carried by Gaur *et al.* (1979) showed that by application of 10 kg low-grade rock phosphate containing 20 per cent P_2O_5 per tonne of organic wastes (crop wastes and leaf fall, etc.) and inoculation with microbial fertilizers improved the nitrogen, phosphorus and humus content appreciably. This can be adopted in improving the compost prepared by mechanical compost plants.

USE OF COMPOSTED VERSUS UNCOMPOSTED MATERIALS

Direct application of carbonaceous materials of wide C/N ratio to soils adversely affects plant growth. This is owing to the utilisation of all soil nitrogen by microorganisms, engaged in the process of decomposition. Mixed organic wastes containing adequate nitrogenous materials like dung and night-soil can, however, be directly applied to land and allowed to decompose *in situ* in soil without causing deficiency of nitrogen and the consequent depressing effect on plant growth. If the C/N ratio of the materials is restored to 30:1 or less, the decomposition in soil is faster owing to dilution and large variety of microbial population of the soil. Positive advantages that accrue from the decomposition carried out in the soil are: (a) no loss of nitrogen in the form of ammonia takes place in the presence of the large quantity of soil; (b) carbon dioxide evolved in large quantities during decomposition assists in enhancing the available plant nutrients of the soil; and (c) production of compounds possessing soil aggregating properties during decomposition by microorganisms, imparts good structure to the soil. The succeeding crop thus derives greater benefit from this manner of application than from the same raw materials after composting. It is, however, obvious that there are some limitations to the use of raw waste materials in practice. Materials like long-straw and street-refuse may be

PREPARATION, PROCESSING AND PRESERVATION

difficult to incorporate without prior disintegration. Offensive materials like night-soil cannot be handled in raw condition. Composting destroys pathogenic organisms and weed seeds that may be present in such materials. Under intensive cropping, the gap between one crop and the other may be too short for direct application of organic materials to soil and they may have to be composted before application. It has, however, been established that whenever possible, direct incorporation of materials like straw, leaves, etc. sufficiently in advance of sowing, with supplementary application of fertilizer nitrogen in adequate quantity, results in marked improvement in soil fertility with significant effect on crop yield.

NIGHT-SOIL POUURETTES

The disposal of night-soil is often a serious problem in towns where facilities for its composting are not available or refuse in adequate quantity is not collected. Trenching the material as such takes a long time for it to dry and causes nuisance of foul smell and profuse fly-breeding. Dehydration of night-soil by mixing it with any absorbing material like soil, ash, dry broken leaves, paddy-husk, etc. is a highly effective method of disposal of this offensive waste which yields poudrette manures of high manurial value. One of the most effective materials for this purpose is sawdust, which has high dehydrating capacity as well as the property of absorbing foul smell. The material can be used whenever available to treat night-soil and obtain an organic manure of high quality. Owing to its low C/N ratio, utilisation of night-soil as such without fermentation yields higher efficiency of response than when it is composted. The question of survival of pathogenic organisms in preparation and use of poudrette manures of this type is, however, a matter warranting consideration and further study.

SUPER-DIGESTED COMPOST

Recent trends in the preparation of farmyard manure and composts include the use of superphosphate which is sprinkled over the raw materials as they are being filled in pits, at the rate of about five per cent. It has been found that the treatment makes organic manures of this type more balanced and markedly reduces losses of nitrogen that take place during decomposition. The availability of phosphorus, thus intimately mixed with organic matter, is higher than when this fertilizer is used as such and this is of particular advantage to acidic, calcareous and heavy soils in which fixation of phosphorus greatly reduces the efficiency of this plant nutrient. Results of work by Walunfkarhar and Acharya (1955) illustrated the effect of super-digested compost on crop growth are given in the following table.

ORGANIC MANURES

Yield of *marua* was significantly better with application of super-digested compost than with separate application of the two :

AVERAGE YIELD OF *Marua* IN G PER POT

Treatment	Grain	Straw	Total
1. No Manure	7.4	23.8	31.2
2. Compost (2½ tonnes dry matter/hectare)	10.3	33.0	43.3
3. Superphosphate (P ₂ O ₅ equal to No. 2)	8.9	30.8	39.7
4. Super-digested compost	12.3	41.6	54.1
5. Compost plus superphosphate (as in No. 4)	10.3	32.6	42.9
S.E.	0.35	1.73	3.18

Subbiah and Surendra Mohan (1964), by the use of tracer technique, showed that the movement of applied phosphorus in soil generally increased when organic matter in the form of compost was also applied with the fertilizer and this was further enhanced when applied as super-digested compost. The increase in movement due to super-digested compost over mere combination of superphosphate and compost was higher in laterite, red and calcareous soils.

CONTROL OF LOSSES OF NITROGEN DURING MANURE PREPARATION

It has been mentioned that the process of decomposition in the preparation of organic manures results in significant losses of nitrogen in practice, which reduces the quality of final manure that is obtained. The losses ranging up to 20 per cent take place although they are heavy in heaps and are considerably reduced in pits. It is, therefore, always desirable to prepare manure in pits to obtain a better quality and quantity of manure.

Loss of nitrogen during fermentation takes place mainly in the form of ammonia gas and methods have been worked out to retain this in the manure by the use of acidic materials to fix nitrogen chemically or by absorbants which physically hold nitrogen. Thus addition of superphosphate at the rate of about five per cent or a heap mineral acid like hydrochloric acid at one per cent have been found to conserve nitrogen in the manure. Materials like charcoal-dust, sawdust, gypsum and even soil added at the rate of five to ten per cent reduce nitrogen losses considerably. The inclusion of this simple treatment in the process of manure preparation would result in obtaining a superior quality of manure in which a substantial amount of nitrogen is held in forms that are highly available to plants.

PREPARATION, PROCESSING AND PRESERVATION

ENRICHED ORGANIC-BASED MANURES

Fermented organic manures are low grade materials and, under Indian conditions, have to be applied in large bulk to obtain significant effects on crop growth and yield. The total nitrogen content in them does not exceed 1.5 per cent at best and with the small quantity of dung used by farmers, it is of the order of 0.5 per cent. The percentage availability of nitrogen for plants in such manures ranges from 5 to 20 per cent with the result that low responses are obtained when applications are made which are inadequate to make good the primary deficiency of nitrogen in our soils.

At the Indian Agricultural Research Institute, a new approach to this problem has been worked out which enables such low-quality manures and other organic materials to be effectively utilized. It has been found that the rate and extent of liberation of nitrogen from applied organic manures is adequate for normal plant growth when their C/N ratio is less than 10 : 1 or the nitrogen content is more than 2.5 per cent. In practice, the C/N ratio of organic materials can be reduced by adding the requisite amount of nitrogen in the form of any nitrogenous fertilizer to it and thereby increasing the value of the denominator instead of decreasing carbon in the numerator by fermentation. Thus, a low-quality manure containing 0.5 per cent nitrogen and a C/N ratio of 20:1 can be treated with ammonium sulphate or urea solution to add 2 per cent more nitrogen and raise the total nitrogen content to 2.5 per cent. This would immediately reduce the C/N ratio to 8:1 and the enriched manure can then be utilised effectively. This method can utilise large quantities of other organic waste materials of wide C/N ratio like dry dung, paddy and groundnut-husks, sawdust, tobacco-waste, wheat-chaff and any material in condition to be easily incorporated in soil. This method enables the process of composting to be eliminated thus saving time and labour.

Enriched organic manures of the above type are processed and get ready in a short time and possess many advantages. Losses resulting from their composting are avoided and the total quantities of organic matter and nitrogen taken initially are conserved and utilised. The decomposition taking place in the soil in the presence of adequate nitrogen incorporated will cause no adverse effects and sufficient nitrogen, in excess of microbial requirements, is liberated for optimum growth of crops.

Variations in the preparation of these enriched manures include incorporation of more nitrogen to obtain concentrated manures containing 5 to 7 per cent nitrogen and supplementing this with superphosphate and potassium sulphate to get mixed organic-mineral fertilizers of any desired grade to suit specific requirements of soil or crops.

ORGANIC MANURES

PREPARATION OF ENRICHED MANURES

Enriched organic-based manures are prepared by taking requisite quantities of nitrogenous and other fertilizers and dissolving them in sufficient water. The solution is then treated with 100 ml of commercial hydrochloric acid per quintal of the final manure for controlling decomposition of the added nitrogen and its retention in the manure. This is then absorbed in the calculated quantity of the organic material, mixed thoroughly and dried in the sun. The dry enriched manure can then be bagged and stored for use.

MICROBIAL METHOD FOR HASTENING COMPOST PREPARATION

Compost is bulky in nature and contains on an average 0.5 to 1.0 per cent N, 0.6 per cent P_2O_5 and 0.5 per cent K_2O . There is a need to reduce its bulkiness and period of composting to make it more acceptable to the farmer. Moreover, the quality of manure should be improved to supply more nitrogen and phosphorus and humus content per unit weight. Researches conducted by Gaur *et al.*, in the Division of Microbiology, I.A.R.I. have shown that it is feasible to hasten the period of composting by proper inoculation with cellulolytic microorganisms as well as improve nitrogen and phosphorus contents of organic fertilizers with low-cost technology. Gaur *et al.* (1981) reported that mesophilic cellulolytic fungi when used as inoculant in composting of plant residues (straw, leaf fall) can hasten the composting process and improve the quality of compost. The carbon content of compost mass was lowered by 25 per cent of the initial raw material (48 per cent) organic carbon during the first month of composting in pits. The loss was more due to fungal inoculation, *Penicillium* spp. showing the maximum decomposition of 46 per cent followed by *Aspergillus* spp. with 37.5 per cent. As a result, C/N ratio within one month was decreased ranging from 19.6 to 23.6 due to inoculation with cellulolytic fungi whereas in uninoculated control, it was 31.4 (Table 22). Subsequently also the decreases in C/N ratio were greater due to inoculation.

The data (Table 23) on recovery percentage of compost on oven dry basis indicated that bulkiness of organic manures decreased by 2 to 8 per cent due to inoculation. The efficient culture reduced bulkiness by 8 per cent. The total nitrogen content showed increase on the other hand, the increase being more in inoculated series. Maximum of 17 per cent increase was recorded with *Aspergillus* spp. (RF₁) followed by *Aspergillus* spp. (IF₁) and *Penicillium* spp. (RF₂) with 15.6 and 14.2 respectively as compared to uninoculated control.

The studies indicated that due to inoculation of compost heaps by cellulolytic cultures the period of composting of dry and wide C/N ratio materials

PREPARATION, PROCESSING AND PRESERVATION

TABLE 22. EFFECT OF CELLULOLYTIC CULTURE IN HASTENING THE PROCESS OF COMPOSTING

Treatments	C.: N ratio of compost sampling interval in months		
	I	II	III
Control	31.4	22.4	20.0
<i>Aspergillus</i> sp. (I _{F₁})	23.6	—	16.8
<i>Trichoderma viride</i> (I _{F₉})	23.1	19.5	18.9
<i>Aspergillus</i> sp. (R _{F₁})	20.6	16.9	14.3
<i>Penicillium</i> sp. (R _{F₂})	19.6	16.8	14.8

Initial C/N ratio 45.7

Weight of raw material — 32 kg/pit

TABLE 23. FINAL YIELD OF COMPOST AND NITROGEN STATUS IN COMPOST MATERIAL

Treatment	Final yield of compost (kg)	% recovery	Total N%	Total N in		% increase over control
				Finished compost material (g)	Per tonne of finished compost (kg)	
Raw material	—	—	1.05	(336)	(10.5)	—
Uninoculated	19.6	61.25	1.41	276	14.1	34.29
<i>Aspergillus</i> sp. (I _{F₁})	18.9	59.06	1.63	308	16.3	55.24 (15.6)
<i>Trichoderma viride</i> (I _{F₉})	18.1	56.56	1.33	241	13.3	26.67 (—5.6)
<i>Aspergillus</i> sp. (R _{F₁})	17.0	53.12	1.65	281	16.5	57.14 (17.0)
<i>Penicillium</i> sp. (R _{F₂})	16.9	52.81	1.61	272	16.1	53.33 (14.2)

Weight of organic material composted 32 kg/pit

Figures in parentheses show increase or decrease over uninoculated control

can be reduced by 4 to 6 weeks. These findings have been confirmed by the studies carried out at other centres.

ORGANIC MANURES

LOW-COST TECHNOLOGY FOR ENRICHMENT OF COMPOST

Recent experiments conducted at I.A.R.I. have shown that inoculation with *Azotobacter chroococcum* and phosphate solubilising microorganisms (*Aspergillus awamori* or *Bacillus polymyxa*) improved the manurial value of compost (Gaur *et al.*, 1978, 1980). Inoculation of compost with nitrogen fixer and P solubiliser was done when the temperature had stabilised around 30-35°C after one month of composting. Low-grade rock phosphate (10 kg/tonne of raw material) was applied at the initial steps of filling up of compost pits.

The results indicated that 31.5 per cent carbon was decomposed in control during the first month whereas the loss in different treatments ranged between 33.3 to 41.5 per cent. This was further increased during second month showing maximum loss of 52.4 per cent of organic carbon in rock phosphate, *Azotobacter* and P solubiliser inoculated series (Table 24). In this treatment C/N ratio was reduced to 14.1 and 12.0 during Ist month and IInd month after inoculation respectively.

There was appreciable gain in nitrogen content per tonne of finished compost in control as well as inoculated series ranging from 60.5 to 111.6 per cent over the initial raw material (Table 25). Addition of powdered rock phosphate alone resulted in an increase of 28.3 per cent over control. Inoculation with *A. chroococcum* and *A. awamori* amended with rock phos-

TABLE 24. CHANGES IN CARBON (%), TOTAL NITROGEN (%), C/N RATIO DURING ENRICHMENT OF COMPOST BY *AZOTOBACTER* AND P SOLUBILIZING CULTURES
(Sampling interval in months after inoculation)

Treatment	Ist month				IInd month			
	Carbon	Nitrogen	C/N ratio	Humus %	Carbon	Nitrogen	C/N ratio	Humus %
Control	31.4	1.36	23.0	7.8	28.5	1.38	20.6	4.85
Control + Rock Phosphate @ 10 kg P ₂ O ₅ /tonne	30.7	1.61	19.0	9.15	27.5	1.77	15.5	6.90
<i>Azotobacter</i> + P solubilizer	30.5	1.51	20.1	9.30	26.6	1.73	15.4	6.00
Rock phosphate + <i>Azotobacter</i> + P solubilizer	26.9	1.89	14.1	9.0	21.9	1.82	12.0	6.95

Initial sample: Organic carbon 46.0%, total nitrogen 0.86%, C/N ratio 53.3.

PREPARATION, PROCESSING AND PRESERVATION

TABLE 25. FINAL YIELD OF COMPOST AND NITROGEN STATUS IN COMPOST MATERIAL

Treatment	Weight of raw material (kg/pit)	Final yield of compost (kg)	% recovery	Total N %	Total N in		% increase over control
					Finished compost material (g)	Per tonne of finished compost (kg)	
Raw material	32	—	—	0.86	275	8.6	—
Control	32	11.85	37.03	1.38	164	13.8	60.46
Rock phosphate @ 10 kg P ₂ O ₅ /tonne	32	12.30	38.44	1.73	213	17.3	101.16
Azotobacter + P solubilizer	32	11.45	35.78	1.77	203	17.7	105.81
Rock phosphate + <i>Azotobacter</i> + P solubilizer	32	13.00	40.63	1.82	236	18.2	11.63

phate showed an increase of 32.0 per cent in nitrogen content over the control resulting in gain of 22 kg N/5 tonnes of finished compost. It was also noted that humus content increased in all the treatments including control (Table 24). The best effect in humus content 9.3% was observed in case of *A. chroococcum* + *A. awamori* after 1 month of inoculation.

In another study the number of *Azotobacter chroococcum* in compost was increased due to its inoculation and use of rock phosphate. The mean numbers of nitrogen fixers of nine weekly intervals per gram of dry compost in different treatments were as follows: Control 1,380, rock phosphate 3,590; *Azotobacter* 6,070; rock phosphate + *Azotobacter* 21,070. This also resulted in an increase in the nitrogen content of compost by 25 to 44 per cent over control. These findings clearly show that quality of compost can be improved by inoculation with *Azotobacter* and P solubilisers suitably amended with rock phosphate.

FLY-BREEDING IN MANURE PREPARATION AND ITS CONTROL

One of the disturbing aspects of manure preparation from organic-wastes particularly town-wastes, is the profuse fly breeding that takes place in this medium. In over-ground heaps, owing to the heat that develops inside, fly maggots migrate and concentrate on the surface few cm all over. If the material is given turnings, as in the Indore method, the maggots get substantially destroyed, otherwise flies develop profusely. In pits, the top layer of refuse or soil becomes the seat of migration of all maggots where they finally develop into flies.

ORGANIC MANURES

The emergence of flies from such manure pits has been observed from the 6th day after filling and goes on till the 12th day or so, after which it ceases. Based on these observations, a simple and highly effective method of destroying flies, while they are resting in the maggot or pupae stage in the surface layer, has been worked out. The entire surface area of the pit is covered on the 6th day after filling with rags, refuse, straw, cotton or other stalks, sawdust, paddy or groundnut-husks or any such combustible waste and set on fire, which may continue to smoulder for about an hour. The maggots and pupae lodged on the few centimetres of upper surface are completely destroyed by the heat. The operation may be repeated on the 12th day to obtain absolute control of fly breeding. The treatment leaves a heat layer of ash on the top which is no more attractive to the flies.

OIL-CAKES

Oil-cake is a valuable by-product of the oilseed extraction industry and contains significant quantities of proteins, of value as animal feed if edible and as nitrogenous manures otherwise. There is always a residue of oil present in them depending on the process of extraction as shown below:

	Oil per cent
Country <i>ghani</i> Extracted	10-12
Hydraulic Press	8-10
Steam Expeller	5-8
Solvent Extract	1-2

The presence of oil slows down decomposition and the process of mineralization of their nitrogen in soil. Since this also gets decomposed in due course, the overall formation of mineral nitrogen is not materially affected in quantity. Their C/N ratio is narrow varying from 3 to 10 and about 60 to 75 per cent of the nitrogen is easily mineralizable and available for plants.

EFFECTIVE UTILISATION OF MAHUA-CAKE

Mahua-cake is the poorest of oil-cakes with a nitrogen content of 2.5 per cent and has been found to be much less effective than others even when applied in larger quantities. It has been found that nitrogen of this manure mineralizes to a small extent in the soil owing to the presence of toxic saponins. The efficiency of the manure can be increased by moistening it and allowing it to ferment for some time to decompose the toxic substances. An effective treatment worked out at the IARI involves treatment of the material with ammonia solution which not only increases the nitrogen content of the manure but enables the original nitrogen to be

PREPARATION, PROCESSING AND PRESERVATION

effectively mineralized and utilized by plants. The treatment could be extended to enrich other oil-cakes and utilize them more effectively.

UTILISATION OF SLAUGHTER-HOUSE WASTES

Blood. Blood is the most valuable of slaughter-house wastes which yields a rich proteinaceous meal on dehydration. It is useful as a feed or as a nitrogenous manure. The existing crude methods of its collection and processing in India result in wastage of a large part.

In slaughter-houses, blood is obtained partly in the form of spongy clots and partly as blood serum in liquid condition. These are dried by heating in large open pans over a slow fire, which is a time-consuming and highly offensive process. The Indian Agricultural Research Institute has worked out a simple method for quick treatment of blood to obtain blood-meal which can be used as feed or as a manure.

Blood-meal from serum is prepared by adding one per cent of lime and then heating it till the temperature rises to 80°C. At this stage, blood begins to coagulate by its reaction with lime, and further slow heating is continued with constant stirring until the flocculated blood separates out and the colour changes from red to ash. The remaining water is decanted off and the coagulated blood is passed through a quarter-inch mesh expanded metal sieve and dried in the sun. There is no loss of nitrogen in the process and the manure contains 10 to 12 per cent nitrogen.

Blood clots are processed separately by cooking them for a few minutes boiling in 0.5 per cent hydrochloric acid solution. The clots harden and rise up to the surface. They are then taken out, rubbed over an expanded metal sieve and dried. The manure contains 14 to 15 per cent nitrogen.

Blood serum can also be absorbed as such in materials like dry dung powder, sawdust, dry leaf powder and such other materials and then dried in the sun. Such products may contain 4 to 5 per cent nitrogen. The use of these absorbing materials on the floor of slaughter-houses would enable blood to be directly absorbed and offers one of the simplest methods of effective collection and utilisation of this waste and keeping slaughter-houses clean.

Waste-meat. This waste in slaughter-house consisting of intestines, offal and other flesh cuttings is hardly utilized in our country. Their disposal and use in compost pits has been suggested where they can serve as a source of nitrogen required for the process of decomposition of other wastes. The proposition of utilization of meat wastes as such and obtaining concentrated meat-meal is more useful to consider. The method of cooking these in steam digesters under pressure can be adopted for the purpose but this requires expensive equipment. A simple method worked out at the

IARI for treatment of such materials consists of cutting them into pieces and cooking in 5 per cent hydrochloric acid solution until they become soft. The material is then washed and rubbed over an expanded metal sieve and dried in the sun. The product may contain 8 to 10 per cent nitrogen and can be used as poultry feed or manure. The cost of processing works out to Rs 2.50 per tonne.

The method can also be adopted to utilize the entire flesh of carcasses of all animals that die in towns and villages and can be organized on a countrywide scale for the exploitation of a valuable source of manure.

Bones. Bones from slaughter-houses, carcasses of all animals and from meat processing industry constitute a valuable waste which could be exploited more fully in the country. The existing methods of disintegration of bones involve crushing them in hammer mills by which raw bone-meal is obtained as a by-product or by digesting them in steam digesters, under pressure which yields steamed bone-meal in fine powdery condition. The methods require expensive equipment and are not always suited for adoption and treating small collection in villages and remote places.

Chemically Processed Bone-meal. The IARI has evolved a purely chemical process of disintegrating bones and obtaining a sterilized bone-meal in fine condition which can be used as a feed or as manure. The process can be worked both as a cottage industry to treat small collections, suiting conditions in this country or on a large scale, if required.

Fresh or dry bones are taken in a suitably-sized container and soaked in sufficient water to cover them. Caustic soda is added to this to make a 5 per cent solution in the quantity of water taken. The bones are stirred once or twice daily until they disintegrate completely to a paste in 14 days. The supernatant is then decanted and utilized again and the disintegrated bones are washed twice with water. The material is finally taken up with water and treated with 10 per cent hydrochloric acid solution until it is neutral to litmus paper. The supernatant is then decanted and the bone paste filtered through muslin cloth. This is then dried in the sun and it yields a sterilized bone-meal in fine condition. The product contains about one per cent nitrogen and 27 per cent phosphoric acid. The cost of production, excluding the value of bones works out to be Rs 60 per tonne. The process is patented.

Fish-meal. Fish manure processed by drying non-edible fish or wastes from fish industry is a well-recognized, balanced organic manure containing both nitrogen and phosphorus in significant quantities. Fish-meal is also produced in India by cooking in steam digesters and then drying. The manure, however, has an extremely offensive smell which stands in the way of its wider use. At the IARI, it has been found that the objectionable

smell can be completely smothered by the use of two litres of pine-oil emulsion per tonne. The long coast-line of the country offers a great scope for fuller exploitation of this highly valuable manure for increasing agricultural production.

Leather-wastes. Tanned and untanned leather wastes are obtained from tannery and leather processing industries where their disposal becomes a serious problem. Leather-wastes can be processed by heating in steam digesters and then grinding to powder. The product obtained contains 7 to 8 per cent nitrogen and has been used as a nitrogenous manure. The IARI has a patented process for preparing leather-meal in which the material is soaked in water and then cooked in 5 per cent hydrochloric acid. The leather disintegrates into a plastic mass which is washed in water and dried and ground to powder. The acid treatment also helps in breaking down complex nitrogenous compounds and yields a manure containing 7 to 8 per cent nitrogen of which 70 to 75 per cent is mineralizable. The method can be adopted on a cottage industry scale, or large-scale according to the needs.

Hair and Wool-wastes. Large quantities of animal-hair wastes become available in tanneries, which have found no use so far. Human hair can be collected in a large quantity, from hair-cutting saloons. These have also not been exploited so far. Large quantities of wool-waste also become available from wool refining, cloth and carpet industries which are not properly utilized. These materials contain about 15 per cent nitrogen in the form of complex keratin and do not decompose in soil when used as such. No estimate is available of the quantities of these wastes that can be collected but it is considered that their utilization in agriculture as manure after suitable processing would provide a substantial additional source of a rich organic manure. A patented process worked out at the IARI involves treatment of these materials with a solution containing 8 per cent caustic soda on the weight of the material. This brings about their disintegration to a paste which is then treated with 10 per cent hydrochloric acid to neutralize the alkali and re-precipitate the proteins. The liquid is decanted and the spongy solid is rubbed over an expanded metal sieve and dried. The product contains 12 to 15 per cent nitrogen and has been found to be a good nitrogenous manure.

VI. BIOGAS POTENTIAL FROM LIVESTOCK WASTES AND HUMAN EXCRETA AND MANURIAL VALUE OF DIGESTED SLURRY AND SLUDGE

ACCORDING to the dung collection survey conducted by Institute of Agricultural Research Statistics, Delhi, it was estimated that in rainy season, 85 per cent of the collected dung was diverted into manure pits and only 13 per cent was converted into dung cakes, whereas during winter season 58 per cent was diverted into manure pits and 40 per cent converted into dung cakes. The dung conversion into dried dung cakes amounted to 32 per cent during summer. However, the disposal of dung for other casual purposes like construction of *kucha* houses, etc. was only 2 per cent in all the seasons (Goel *et al.*, 1973). The all-India average of the collected dung being used for preparing dung cakes is approximately 29 per cent which amounts to about 290 million tonnes of dung being burnt away by farmers as fuel for cooking. The solution to the problem of alternate

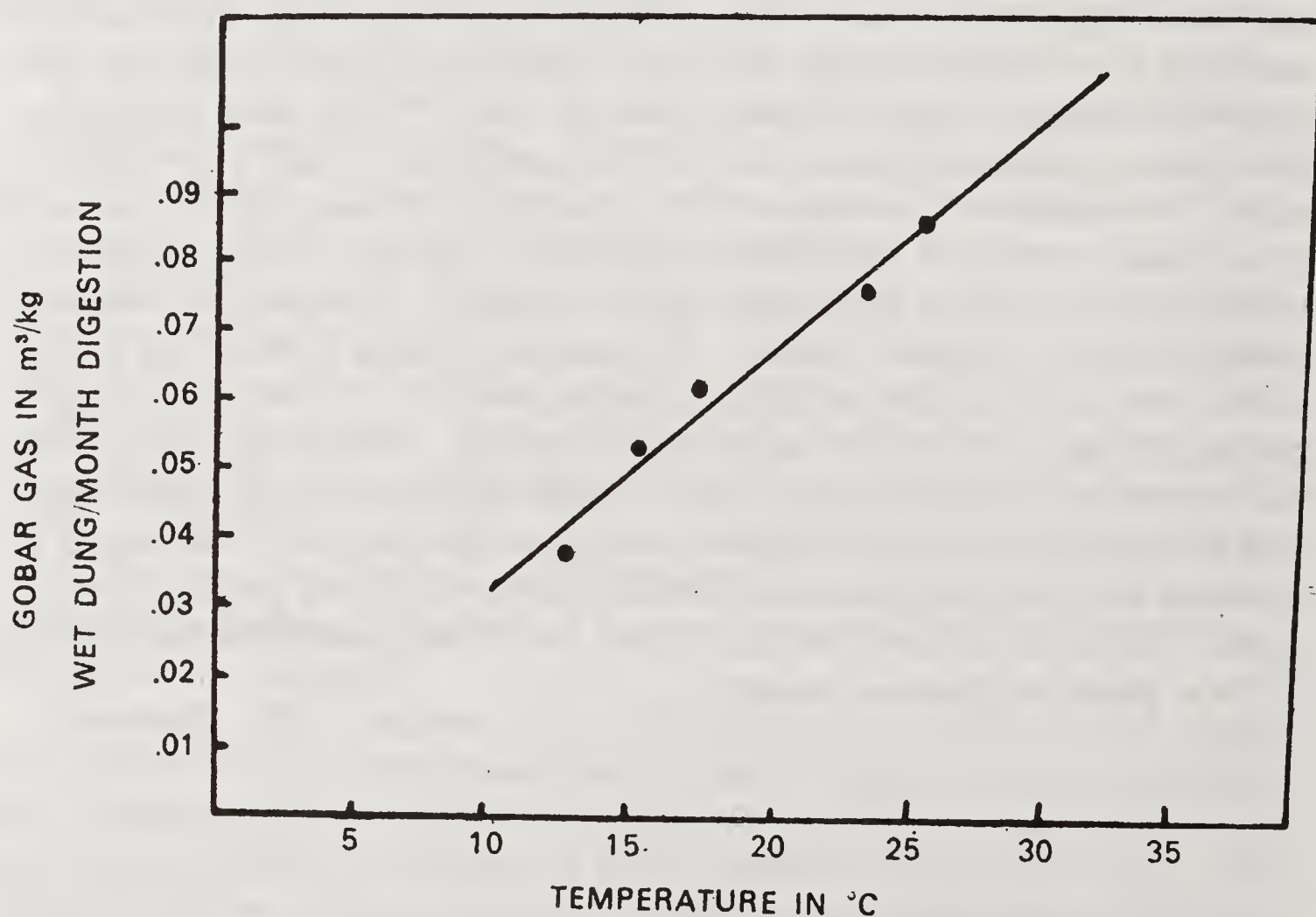


Fig. 1 Rate of gobar-gas production at different temperatures (Acharya 1957)

BIOGAS POTENTIAL FROM LIVESTOCK

fuel supply to rural farmers has to be tackled with more fire-wood production or other available sources, so that the dried dung cakes may not be burnt away into ash losing the manurial components in them. Acharya (1957) and Idnani and Varadarajan (1974) have reviewed the work on gobar-gas production in India and recommended that the anaerobic digestion of cattle dung in biogas plants would yield fuel as well as manure. The rate of gas production from cattle dung during two months' digestion in gobar-

TABLE 26. POTENTIAL BIOGAS PRODUCTION FROM BOVINE DUNG IN DIFFERENT STATES OF INDIA

S. No.	State/ Union Territory	Monthly mean temperature (°C)		Rate of gas production (cu m/tonne wet dung)	Annual dung availability (million tonnes)	Annual gas production (million cu m)
		minimum	maximum			
1.	Andhra Pradesh	22.8	33.7	75.0	77.389	5804.175
2.	Assam	16.8	29.4	64.0	25.376	1624.064
3.	Bihar	17.0	31.7	68.0	68.557	4661.876
4.	Gujarat	20.7	32.6	71.0	38.262	2716.602
5.	Haryana	13.5	34.2	66.3	32.213	2135.722
6.	Himachal Pradesh	10.7	28.7	52.3	19.181	1003.166
7.	Jammu and Kashmir	3.2	21.0	23.2	9.725	225.620
8.	Karnataka	21.9	29.4	69.3	54.800	3797.640
9.	Kerala	26.6	28.8	74.0	4.538	335.812
10.	Madhya Pradesh	17.7	33.3	67.2	80.732	5425.190
11.	Maharashtra	21.2	30.8	68.7	107.986	7418.638
12.	Manipur	16.8	29.4	64.0	1.285	82.240
13.	Meghalaya	16.8	29.4	64.0	1.779	113.856
14.	Nagaland	16.8	29.4	64.0	0.348	22.272
15.	Orissa	20.6	31.3	72.8	51.498	3749.054
16.	Punjab	13.5	34.2	66.3	51.190	3393.897
17.	Rajasthan	15.8	33.7	69.3	77.896	5421.562
18.	Tamil Nadu	24.7	31.6	77.3	70.027	5413.087
19.	Tripura	16.8	29.4	64.0	1.895	121.280
20.	Uttar Pradesh	15.1	32.9	61.1	179.032	10938.855
21.	West Bengal	18.1	29.7	66.3	45.687	3029.048
22.	Andaman Nicobar Islands	28.9	31.3	82.7	0.043	3.556
23.	Chandigarh	13.5	34.2	66.3	0.127	8.420
24.	Dadra and Nagar Haveli	28.9	31.3	82.7	0.070	5.789
25.	Delhi	13.5	34.2	66.3	1.372	90.964
26.	Goa, Daman and Diu	28.9	31.3	82.7	1.007	69.181
27.	Lakshadweep	28.9	31.3	82.7	0.006	0.496
28.	Mizoram	16.8	29.4	64.0	0.090	5.760
29.	Pondicherry	24.7	31.6	77.3	0.476	36.795
All India Average		—	—	67.1	—	—
All India Total		—	—	—	1002.587	67654.617

ORGANIC MANURES

gas plants at different temperature conditions is graphically represented in Fig. 1. Assuming the above gas production rate for different States of India depending upon the temperature variations over a period of year, the statewise mean temperature and rate of gas production and annual production potential of biogas from bovine dung are presented in Table 26. The mean temperature in southern, eastern and western States and Islands in India vary with minimum temperature range of 18.1 to 28.9 °C during winter and maximum temperature of 28.8 to 33.7 °C during summer. The monthly mean temperature in northern States vary with minimum temperature range of 3.2 to 17.0 °C during winter and maximum temperature of 21.0 to 34.2 °C during summer. Hence, the rate of biogas production per tonne wet dung varied from 64.0 to 82.7 cu m in western, eastern and southern States and 23.2 to 66.3 cu m in northern States. The annual biogas potential works out to be 67,654.617 million cu m. The gas production from solid excreta of goat and sheep was calculated at the rate of double the gas yield from cattle dung due to roughly double the dry matter content in fresh dung. The biogas yield from excreta of poultry, pig, other livestock and human beings was also calculated at double the

TABLE 27. POTENTIAL BIOGAS PRODUCTION FROM OTHER LIVESTOCK EXCRETA AND HUMAN EXCRETA IN INDIA

Source	Annual excreta (million tonnes)	Annual biogas potential (million cu m)
Sheep and goats	12.228	1640.998
Pigs	2.298	308.392
Other livestock	3.395	455.609
	6.024	808.420
Human beings	31.554	4234.547
Total	55.499	7447.583

TABLE 28. POTENTIAL ELECTRICAL ENERGY FROM BIOGAS PER ANNUM IN INDIA

Source of excreta	Biogas (million cu m)	Electrical energy (billion kwh)	Effective energy (billion kwh)
Cattle	67654.617	108.586	86.869
Other livestock	3213.419	5.158	4.126
Human beings	4234.547	6.796	5.436
Total	75102.583	120.540	96.431

BIOGAS POTENTIAL FROM LIVESTOCK

rate of biogas yield due to the higher digestible organic matter content in cattle excreta (Sharma, 1976; Bansal *et al.*, 1977).

The biogas potential from livestock excreta other than cattle and buffalo and human excreta would be 7,447.583 million cu m (Table 27). The potential power generation from the biogas that can be obtained from all the livestock and human excreta was calculated on the basis of power generation of 1.605 kwh electricity produced from 1 cu m gas and presented in Table 28.

Rao (1961) reported on the potential for generation of power from biogas in India. The use of dung cakes in India has been estimated to yield 12.9 billion kwh effective energy for domestic fuel (NCAER, 1965). If all the available livestock and human excreta were used for biogas production, the total biogas yield of 75,102.583 million cu m would produce 120.540 billion kwh electrical energy having 80 per cent effective consumption, which will be equivalent to 96.431 billion kwh (Rao, 1961). According to the estimate of National Council of Applied Economic Research, the effective energy requirement in rural sector of India would be of the order of about 125 billion kwh and would meet about 77 per cent of the rural fuel requirement of India.

According to Khadi Village Industries Commission (1975), the cost of constructing a 6 cu m biogas plant is about Rs 4,200.00. The installation charges including construction material and labour costed 46 per cent whereas the gas holder and guide frame costed nearly 43 per cent, and 11 per cent of the cost was required for the pipeline and gas stove and lamp. The annual profit derived from the 6 cu m biogas plant was reported to be about four hundred and eighty rupees.

A higher percentage profit can be obtained, if the cost of the biogas plant can be reduced. The Chinese-based Janata biogas plant fabricated at Gobar Gas Research Station, Planning Research Action Division, Ajitmal does not require the gas holder and guide frame and costs only 50-60 per cent of the KVIC design.

The digested slurry has higher manurial value with a narrow C:N ratio. So, the available livestock and human excreta can be profitably utilized for biogas production to meet the rural energy requirement and to obtain better quality manure as well as minimize the environmental pollution.

Manurial Value of Digested Slurry

The digested dung slurry has a low content of N, P and K as compared to commercial fertilizer, but it is a valuable source of human substances and micronutrients. During anaerobic digestion of cattle dung 15 to 30

ORGANIC MANURES

per cent protein-nitrogen is mineralised to ammoniacal form.

The average composition of digested cattle dung slurry is summarised in Table 29. The slurry or sludge can be composted with waste organic materials of high dry matter content for easy distribution and utilisation as manure.

TABLE 29. COMPOSITION OF DIGESTED CATTLE DUNG SLURRY

Item	D.M. %	O.M. %	Carbon %	Total N%	P%	C:N ratio	Reference
Digested cattle dung	8.0	72.57	42.1	2.07	0.35	20.47	Mann <i>et al.</i> , 1972
	5.5	60.68	35.2	1.81	0.40	19.4	Laura and Idnani, 1972
	8.2	71.80	37.5	2.12	0.41	17.6	Chetan Parkash, 1976

The digested cattle dung slurry from a 1,000 cu ft biogas plant was composted in a battery of three manure pits with alternate layers of weeds, garden cuttings and other farm wastes (Neelakantan, 1973). The samples of cattle dung and the two months old digested slurry and 4 months old compost were periodically analysed for chemical components in a year. It was found that on an average 13 per cent total carbon was digested during two months of anaerobic digestion of cattle dung.

The chemical analysis of the cattle dung, digested slurry and compost is presented in Table 30.

TABLE 30. CHEMICAL COMPOSITION OF CATTLE DUNG, DIGESTED SLURRY AND COMPOST

Type of manure	Dry matter (%)	Ash (%)	C (%)	N (%)	P (%)	C:N ratio
Dung	20.03	17.67	47.76	1.55	0.76	36.76
Digested slurry	5.73	22.60	41.56	1.99	1.02	23.19
Compost	30.82	38.32	36.36	2.24	1.20	16.73

Laura and Idnani (1972) composted the nitrogen deficient wheat straw and sorghum fodder with spent (digested) slurry under anaerobic conditions. Addition of spent slurry accelerated decomposition of wheat straw during 45 days digestion from 10 to 30 per cent and that of sorghum fodder from 15 to 40 per cent of dry matter.

BIOGAS POTENTIAL FROM LIVESTOCK

Acharya (1957) reported that the manure produced by anaerobic digestion showed good manurial value after sun-drying and was found to be better than farmyard manure (Table 31). In wet conditions, the manurial value of digested cattle dung slurry was less than that after sun-drying. Table 31 presents the yield of crops with wet and sun-dried digested slurry, farmyard manure and nitrogen application @ 100 lb N/ha.

TABLE 31. CROP YIELD ON APPLICATION OF WET AND SUN-DRIED DIGESTED CATTLE DUNG SLURRY IN POT CULTURE TRIAL (G/POT)

Treatment	Wheat		<i>Ragi</i>		Sunn hemp (Dry wt)
	Grain	Straw	Grain	Straw	
1. No manure	8.84	13.46	10.1	31.4	93.4
2. Wet slurry	10.32	15.26	12.0	33.8	106.3
3. Sun-dried slurry	11.31	17.39	13.6	36.8	117.2
4. FYM	10.02	16.28	12.4	34.6	104.4
5. Ammonium sulphate	13.70	19.55	15.4	41.2	121.2

Ghosh and Dutta (1977) reported that the digested slurry in wet and dried form gave significantly higher yield of rice and berseem as also with farmyard manure and groundnut cake (Table 33). The residual effect of slurry was observed for two years, though the magnitude of response gradually narrowed down. Neelakantan *et al.* (1978) reported on the effect of fresh and sun-dried digested cattle dung slurry @ 1 and 2 per cent level on oat in sand and soil under greenhouse conditions. The positive effect on fodder yield in soil culture was found to be of a lesser degree than sand culture. The results also showed that fresh slurry was better than dried slurry and the effect was more marked in sand culture (Table 32).

TABLE 32. GREEN FODDER YIELD OF OAT (G/POT)

Treatment	Sand culture	Soil culture
Control	19.2	14.7
Fresh dung (1 %)	54.6	34.6
Fresh dung (2 %)	66.0	40.0
Fresh slurry (1 %)	73.3	43.3
Fresh slurry (2 %)	89.3	56.7
Dried slurry (1 %)	48.0	37.3
Dried slurry (2 %)	53.3	45.1

ORGANIC MANURES

TABLE 33. MEAN YIELD OF RICE (G) AND BERSEEM (DRY FODDER) AND TOTAL UPTAKE OF NITROGEN BY CROP

Source (112 kg N/ha)	Average of first three years		Average of next three years			
	Yield g/pot		Total uptake of N g/pot		Mean yield of residual crop g/pot	
	Rice	Berseem	Rice	Berseem	Rice	Berseem
Wet slurry	20.4	18.4	383	590	11.8	14.4
Dried slurry	24.4	23.1	410	650	12.9	15.0
Farmyard manure	21.9	22.8	383	610	11.7	14.2
Groundnut cake	50.8	18.3	877	557	7.6	7.3
Ammonium sulphate	43.2	13.4	813	406	7.5	8.3
No manure	17.8	16.0	330	507	6.6	10.1
C.D. at 5% level	2.5	2.2	52	72	4.1	4.0

In micro-plot experiment with oat and maize, the fresh slurry, dried slurry and dung application was compared with 0, 20, 40 and 60 kg nitrogen application/ha and the results are presented in Table 34.

TABLE 34. YIELD OF OAT FODDER WITH APPLICATION OF DUNG, DIGESTED FRESH SLURRY, DRIED SLURRY AND NITROGEN

Treatment	Fodder yield (q/ha)	
	Maize	Oat
Control	228.5	272.6
N ₂₀	250.2	282.6
N ₄₀	284.8	295.1
N ₆₀	337.8	335.7
Dung (0.125%)	—	274.0
Fresh slurry (0.125%)	—	311.5
Fresh slurry (0.25%)	266.7	—
Fresh slurry (0.5%)	286.9	—
Dried slurry (0.125%)	—	292.1

The application of fresh and dried slurry at 0.125 per cent level in respect of yield of oat was comparable to 20 and 40 kg nitrogen application. The effect of application of 0.25 and 0.50 per cent fresh digested slurry was evaluated and presented in Table 34 (Neelakantan *et al.* 1978). The response on application of slurry at 0.25 per cent and 0.50 per cent was comparable to 40 kg N application/ha.

VII. RECYCLING OF ORGANIC MATERIALS AS FERTILIZERS

ORGANIC wastes and surplus crop residues can be recycled in soil by different methods such as *in situ* incorporation of organic matter or by organic mulch besides composting which will eventually improve the biological, chemical and physical properties of soil resulting in higher crop productivity. Each season/year substantial quantities of plant nutrients are removed from soil by crop harvesting (Dhar, 1978). On an average, one tonne of grain along with straw of wheat, paddy, jowar, bajra, maize and barley are likely to remove 33 kg N, 12 kg of P_2O_5 and 58 kg of K_2O . Therefore, estimated 125 million tonnes of foodgrains produced in the country will remove about 12.9 million tonnes of plant nutrients. The nutrient supply through chemical fertilizers during 1977-78 was of the order of 4.29 million tonnes only. Thus the balance of 8.61 million tonnes has to be met through organic sources. In this context recycling of organic wastes/by-product becomes vital for returning back at least a part of plant nutrients drawn from soil for maintaining humus and the soil productivity.

Direct incorporation of organic materials in soil and their effects

Organic materials of different sorts can be ploughed in the soil (0-20 cm layer) about 3-4 weeks prior to sowing of crop with optimum moisture level. The prior decomposition of organic materials is important to ensure benefit to the crop and without nitrogen immobilisation by microorganisms. The rate of decomposition will depend on the nature of organics used. Leguminous residues and non-edible cakes will mineralise faster as compared to cereal residues/straw (Gaur *et al.*, 1970, 1971, 1972). Addition of nitrogen in the form of chemical fertilizers or non-edible cakes will accelerate the pace of mineralisation of cereal residues/straw poor in nitrogen. On the other hand, mineralisation of humified FYM or compost is slow and steady process and acts as a slow release fertilizer. It can be incorporated in soil even just before sowing of the crops. The studies have shown that application of farmyard manure or compost is the best source for maintenance of soil organic matter in Indian soils. The next in order is cereal straw/residues for the maintenance of organic matter in soil. Legume residues are not good for maintenance of soil organic matter in tropics but are good sources of plant nutrients, specially nitrogen and they may add as much as 40 kg N/ha in one season. The favourable effect of farmyard manure in building soil fertility has been clearly demonstrated in manurial experiments in progress in India and elsewhere.

Maintenance of organic matter in Indian soils

Controlled incubation studies conducted in different Indian soils for about 6 months have indicated that the application of FYM at the rate of 44 tonnes/ha (0.5 per cent carbon basis) effectively builds up the organic matter status of different soils whereas the control soils lost 15 to 40 per cent of the organic carbon (Anonymous, 1970; Gaur *et al.*, 1970). In case of cereal residues the quantity to be applied at the above rate for maintenance of soil organic matter comes to 24.5 tonnes/ha and higher doses than 25 tonnes/ha are needed for effective increase. The addition of farmyard manure and crop residues increased the soil carbon in different soil groups by 10 to 40 per cent. These findings were supported by the data obtained from soil samples of various permanent manurial trials conducted at Sabour (Bihar), Chinsurah (West Bengal), Gurdaspur (Punjab) and Kanpur (U.P.) and analysed during 1972 (Anonymous, 1972). The best results were obtained in the experiment conducted at Sabour where the application of 18.9 tonnes and 75.5 tonnes of FYM/ha/crop increased soil organic carbon by three times (1.230%) and five times (1.930%) respectively as compared to control (0.378%). Humic and fulvic acid carbon percentages were almost doubled in case of 18.9 tonnes FYM/ha/crop as compared to control whereas this fraction was four times in case of 75.5 tonnes FYM/ha/crop. Organic nitrogen increased three times by addition of 75.5 tonnes FYM/ha/crop over control. However, the difference between 75.5 tonnes FYM/ha applied in one lot and 18.9 tonnes FYM/ha/crop as regards nitrogen content was not much different.

Effect of organic matter on soil microorganisms

The results with different types of organic materials have clearly shown that living phase of soil was greatly stimulated which will be of consequence not only in biodegradation but also in nitrogen fixation, phosphorus solubilisation and in increasing the availability of plant nutrients to crops. Phosphorus is non-renewable asset and nitrogen is more labile and subject to losses. The augmented microbial activity can tap the inert nitrogen gas from the atmosphere, reduce the leaching losses and regulate the supply of phosphorus. The zymogenous response of microflora varied with the type and characteristics of soil and organics used. Bacteria due to application of organics was influenced to a greater extent than fungi and actinomycetes (Tables 35-37). Asymbiotic nitrogen fixers (*Azotobacter* and anaerobes) were stimulated by addition of straw in the field soil at 2, 5 and 10 tonnes/ha (Mukherjee and Gaur, 1980), Fig. 2. The regulated application of organics as a practice will energise the living microorganisms of

TABLE 35. AVERAGE BACTERIAL POPULATION IN DIFFERENTIALLY TREATED SOILS DURING ORGANIC MATTER DECOMPOSITION (POPULATION EXPRESSED IN 10⁶/G SOIL)

Soils	Control (Soil)	Treatments						
		F.Y.M.		Wheat straw/paddy straw		Bajra stalk/Maize stalk		
		0.5%C	2.0%C	0.5%C	2.0%C	0.5%	2.0%	2.0%
Hilly soil (H.P.)	28.63	26.66	52.93	57.46	88.82	—	—	—
Alkali soil (Delhi)	3.39	8.79	29.60	17.37	29.17	—	—	—
Heavy clay soil (Patna)	11.66	16.54	17.56	24.69	28.71	20.09	28.39	28.39
Acid red loam (Kanke)	5.06	20.51	23.51	12.77	17.41	24.97	28.11	28.11
Sierozem soil (Hissar)	31.10	51.30	73.53	—	—	54.48	78.10	78.10
Alkali soil (Rajthal)	0.35	0.51	1.13	—	—	0.62	1.83	1.83
Alluvial soil (CRRRI)	32.08	74.83	141.18	92.12 (88.41)	197.76 (193.75)	—	—	—
Hebbal red soil	16.38	20.52	39.20	—	—	228.89	367.41	367.41
Medium black soil	3.85	2.45	2.51	1.78	3.36	—	—	—
Acidic lateritic	5.12	4.56	3.07	1.63	3.61	—	—	—

TABLE 36. AVERAGE ACTINOMYCETE POPULATION IN DIFFERENTIALLY TREATED SOILS DURING ORGANIC MATTER DECOMPOSITION (POPULATION EXPRESSED IN 10⁶/G SOIL)

Soils	Control (Soil)	Treatments							
		F.Y.M.		Wheat straw/paddy straw		Bajra stalk/maize stalk			
		0.5%C	2.0%C	0.5%C	2.0%C	0.5%C	2.0%C	0.5%C	0.2%C
Hilly soil (H.P.)	8.93	11.23	20.79	20.51	30.23	—	—	—	—
Alkali soil (Delhi)	0.67	2.60	16.27	3.74	6.56	—	—	—	—
Heavy clay soil (Patna)	2.26	3.10	3.46	4.41	5.06	4.21	4.79	4.21	4.79
Acid red loam (Kanke)	1.52	1.84	2.21	1.78	2.29	2.38	2.74	2.38	2.74
Sierozem soil	13.47	37.44	55.83	—	—	52.26	102.75	52.26	102.75
Alkali soil (10 ³)	15.98	15.51	30.41	—	—	15.29	14.19	15.29	14.19
Alluvial soil (CRR)	3.22	9.74	16.08	8.77 (9.35)	13.24 (12.38)	—	—	—	—
Medium black soil (Poona)	1.62	1.10	1.56	1.09	1.94	—	—	—	—
Acidic lateritic	3.29	4.26	3.60	2.98	1.72	—	—	—	—
Hebbal red soil (10 ⁵)	8.44	5.94	9.39	—	—	12.47	11.69	12.47	11.69

TABLE 37. AVERAGE FUNGAL POPULATION IN DIFFERENTIALLY TREATED SOILS DURING ORGANIC MATTER DECOMPOSITION (POPULATION EXPRESSED IN 10^4 /G SOIL)

Soils	Control (Soil)	Treatments					
		F.Y.M.		Wheat straw/paddy straw		Bajra stalk/maize stalk	
		0.5%C	2.0%C	0.5%C	2.0%C	0.5%C	2.0%C
Hilly soil (H.P.)	11.57	14.54	17.57	17.11	28.96	—	—
Alkali soil (Delhi)	4.64	6.26	5.23	12.25	27.14	—	—
Heavy clay soil (Patna)	12.39	13.54	13.66	18.26	28.34	55.91	73.32
Acid red loam (Kanke)	10.82	12.35	12.84	29.57	57.02	72.69	99.39
Sierozem soil	28.69	25.46	24.98	—	—	43.36	40.30
Alluvial soil (CRR)	27.15	39.00	48.23	75.54 (90.08)	134.15 (114.92)	—	—
Alkali soil (Hissar)	1.68	1.84	1.82	—	—	12.98	2.56
Hebbal red soil	6.74	4.06	4.89	—	—	42.43	95.55
Medium black soil (Poona)	13.29	11.71	13.38	13.21	12.68	—	—
Acidic lateritic	18.07	14.41	14.54	17.54	26.29	—	—

ORGANIC MANURES

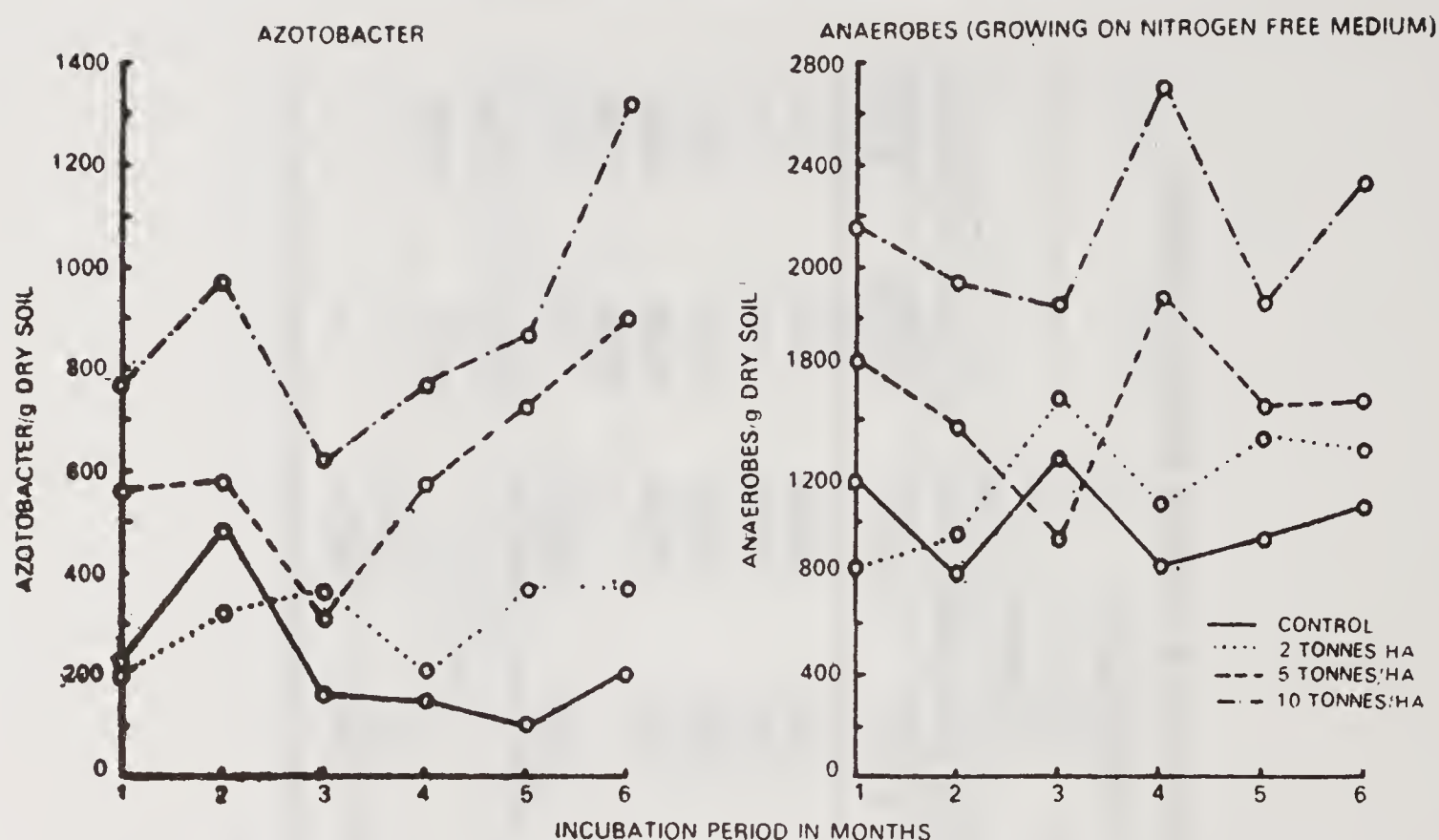


Fig. 2. Effect of incorporation of wheat straw on the nitrogen fixing microorganisms

the soil, involved in biochemical activity of importance to soil fertility and plant nutrition. Addition of FYM and crop residues resulted in increase of total nitrogen varying from 10 to 70 per cent depending on the plant material and soil type used.

Immobilisation of nitrogen was usually associated with high C/N ratio material. Immobilisation was not observed when its C/N ratio was brought down to 40 and mineralisation of nitrogen was satisfactory and steady. The addition of chemical nitrogen or organic comparatively richer in nitrogen like non-edible cakes (*neem*, *karanj*), legumes and grasses can be advantageously utilised for lowering the C/N ratio of cereal straw/residues. Addition of rock phosphate or superphosphate was found beneficial in hastening the *in situ* decomposition of organic material in soil and increased the available phosphorus. Farmyard manure application invariably increased the availability of phosphates.

Organic Mulch

This is a unique and simple method particularly for recycling of dry and nitrogen-poor organic materials since its incorporation in soil is not required at this stage and the costs of ploughing, water and inputs of chemical fertilizer for their favourable utilisation is not involved. Although decomposition of mulch is a slow process, its biomass and C/N ratio during the course of one crop season is appreciably reduced and this facilitates its incorporation in next season at a low cost. The experiments have shown

TABLE 38. EFFECT OF ORGANIC MULCHING WITH PADDY/WHEAT STRAW YIELD OF FIELD GROWN WHEAT AND PEA CROPS

Crop	Per cent increase in yield in					
	Bangalore red sandy loam	Barrackpore alluvial soil	Hissar Sierozem soil	Poona medium black soil	Acidic soil	Loam (Kanke)
Wheat	31.6	67.0	66.0	—	14.3 ^a	22.9 ^b
Pea	29.4	9.60	—	13.4	—	77.6 ^b
Maize	—	—	—	—	5.00 ^c	21.2 ^a
Moong	—	—	—	—	—	—
a. Mulched with paddy straw.						16.1 ^e
b. Mulched with karanj leaves.						—
c. Mulched material incorporated in soil, previous crop-wheat.						95.7
d. Mulched material incorporated in soil, previous crop-peas.						31.7
e. Mulched material incorporated in soil, previous crop-maize.						—

TABLE 39. EFFECT OF MULCHING ON THE YIELD AND NITROGEN UPTAKE BY GRAIN IN CROPS

Treatment	Grain yield (g/plot)	% increase over unmulched treatment	Dry matter yield (kg/plot)	% increase over unmulched treatment	Grain nitrogen %	Uptake of nitrogen by grain (g/plot)
<i>Moong</i>						
Unmulched	84.5	—	4.0	—	3.3	2.8
Mulched						
Significant at 5%	111.3	31.6	5.0	26.2	3.4	3.8
<i>Maize</i>						
Unmulched	325.0	—	3.6	—	1.6	5.3
Mulched						
Significant at 5%	684.2	110.5	4.5	26.5	1.7	11.7

TABLE 40. EFFECT OF STRAW MULCH ON SOIL MICROBIAL POPULATION

Treatment	Moong crop (Average values of 3 intervals)			Maize crop (Average values of 3 intervals)		
	Bacteria	<i>Azotobacter</i>	Actinomy- cetes	Bacteria	<i>Azotobacter</i>	Fungi
Fallow unmulched	1 × 10 ⁶ 11.73	1 × 10 ² 5.5	1 × 10 ⁵ 7.53	1 × 10 ⁶ 12.86	1 × 10 ² 4.83	1 × 10 ⁴ 4.46
Fallow mulched	28.6	9.33	26.33	40.06	18.3	12.7
Cropped unmulched	17.66	5.03	13.26	20.2	3.86	5.3
Cropped mulched	32.96	8.0	24.66	38.93	13.63	11.0

that straw mulch besides controlling the weeds and conserving moisture and thereby saving irrigation, also increases crop yield and population of beneficial soil microflora.

The yields of wheat crop by mulching with straw was increased in acidic-red-loam, sierozem and laterite soils by 14.3, 24 and 29 per cent over unmulched treatment under different conditions. Mulching showed better effect on pea crop in acidic red-loam, medium black and laterite soils and increased the grain yield by 77.6, 43 and 40 per cent, respectively. Trials were repeated in different agro-climatic conditions (Bangalore red sandy loam, Ranchi acidic red, Poona medium black, Hissar sierozem, Delhi and Barrackpur alluvial soils) on wheat, pea, *moong* and maize crop (Gaur, 1975; Gaur and Mukherjee, 1980). The previous year's findings were confirmed showing the beneficial effect of wheat or paddy straw or *karanj* leaves mulch at 10 tonnes/ha on the crops (Table 38). The grain yield of wheat was increased by 66 to 67 per cent in sierozem and Barrackpur alluvial soil, by 31.6 per cent in red sandy loam, 14.3 per cent in acidic red loam and 4.2 per cent in medium black soil. Pea grain yield was increased by 77.6, 29.4, 13.4 and 9.6 per cent in acidic red loam, red sandy loam, medium black and Barrackpur alluvial soil, respectively. The grain yield of *moong* and maize (Table 39) was increased significantly in Delhi alluvial soil due to wheat straw mulch by 31.7 and 110.5 per cent, respectively (Gaur and Mukherjee, 1980). The incorporation of mulched material used on previous crop — maize, in soil increased the grain yield of wheat crop by 16.1 per cent. Nitrogen uptake by both these crops was increased and mulching had favourable effect on the population of soil bacteria, fungi and actinomycetes (Table 40). The population of nitrogen fixers (Table 40) and phosphate solubilisers were increased several-folds. Organic mulch acts in several ways on soil and crop: (i) enhances number of soil microflora, (ii) increases plant nutrient availability, (iii) conserves soil moisture, (iv) controls weeds, (v) regulates soil temperature, and (vi) augments crop yields.

Effect of crop residues on yield of legume crops

The direct utilisation of organics low in nitrogen, i.e. high C/N ratio material may not always be feasible in intensive agriculture and particularly in culture of cereal crops. The utilisation of organic materials in soil in case of cereals requires proper understanding of the technology by the farmer. While growing legume crops which have got host-*Rhizobium* symbiosis system i.e. fixing of nitrogen in the nodules by rhizobia for the supply to plant, is not affected with nitrogen immobilisation processes which generally occurs when organic matter low in nitrogen is ploughed in the soil. On the other hand, this benefits the process of nitrogen fixation. More-

TABLE 41. EFFECT OF STRAW ON THE NODULATION OF GROUNDNUT CROP

Treatment	Sampling period in weeks					
	4th week			7th week		
	No. of nodules	Dry wt of nodules (mg)	Dry wt of plants (g)	No. of nodules	Dry wt of nodules (mg)	Dry wt of plants (g)
Control	68	31	3.60	115	51	7.7
Wheat straw tonnes/ha	82	54 (74.2)	4.50 (25.0)	165	89 (74.5)	10.8 (40.0)
Wheat straw 5 tonnes/ha	125	103 (232.3)	5.87 (63.1)	223	148 (190.2)	16.9 (120.0)
Wheat straw 10 tonnes/ha	58	30 (—)	3.43 (—4.7)	101	66 (29.4)	9.6 (25.2)
CD at 5% level	20	12	0.65	29	17	1.9

Values in parantheses indicate % increase over control.

TABLE 42. EFFECT OF STRAW ON THE YIELD, NITROGEN UPTAKE AND OIL CONTENT OF
GROUNDNUT CROP AND YIELD OF WHEAT CROP

Treatment	Groundnut						Wheat		
	Pod yield (g/plot)	Dry matter yield (g/plot)	Nitrogen % in pod	Nitrogen uptake by pod (g/plot)	Nitrogen % of dry matter	Nitrogen uptake by dry matter (g/plot)	Oil %	Grain yield (g/plot)	Straw yield (kg/plot)
Control	336.7	840.0	3.95	13.3	0.36	3.0	47.6	760	1.53
Wheat straw	560.0	1170.0	4.03	22.6	0.39	4.6	48.2	790	1.86
2 tonnes/ha	(66.3)	(39.3)						(3.9)	(20.0)
Wheat straw	658.3	1473.3	4.10	27.0	0.40	5.9	48.4	890	2.13
5 tonnes/ha	(55.5)	(75.4)						(17.1)	(37.4)
Wheat straw	471.7	996.7	4.03	19.0	0.39	3.9	49.4	1040	2.41
10 tonnes/ha	(40.1)	(18.7)						(36.8)	(55.5)
CD at 5% level	53.7	136.6						196	0.265

Values in parenthesis indicate % increase over control.

TABLE 43. EFFECT OF ORGANIC MATERIALS ON YIELD AND NITROGEN UPTAKE BY MAIZE CROP

Treatment	Grain yield (q/ha)	Straw yield (q/ha)	Grains N (%)	Grain N uptake (kg/ha)
Control	48.0	160.0	1.58	73.4
N (200 kg N/ha)	62.2	200.0	1.73	107.7
Straw (0—15 cm depth) + N	62.6	220.0	1.68	105.1
Straw (0—7.5 cm depth) + N	55.6	230.0	1.73	96.2
Straw + neem cake (0—15 cm depth) + N	76.0	270.0	1.75	133.5
FYM (0—15 cm depth) + N	70.4	240.0	1.63	114.8
CD at 5%	11.0	52.0		



Fig. 3. Growth of groundnut plants was influenced by the application of straw

over, the beneficial effects can be obtained by improvement of soil conditions, nitrogen immobilisation and greater supply of carbon dioxide to plants for production of sufficient photosynthates. This method of recycling can be carried out by ploughing straw one week before sowing with small dosage of nitrogen (10-20 kg N/ha) and phosphate (90 kg P_2O_5 /ha) as recommended for leguminous crops.

Nodulation in groundnut crop (Table 41) was improved due to application of wheat straw at 2, 5 and 10 tonnes per hectare in Delhi alluvial soil (Gaur and Mukherjee, 1979). Pod yield (Table 42) was significantly increased by 66 and 95 per cent due to application of 2 and 5 tonnes straw per hectare by this method. Growth of plants was favourably influenced by 5 tonnes straw application (Fig. 3). The residual effect of straw incorporation after groundnut increased the wheat grain yield by 3.9 to 36.8 per cent. Maximum residual effect was obtained with 10 tonnes straw applied per hectare. The practice can be followed in legume-cereal rotation. The straw gets decomposed during the growth period of legume crops and residual effect can be observed on the following crop. This has been confirmed with other legume crops (lentil, peas and *moong*).

Effect of straw, neem cake and farmyard manure on yield of maize crop

A field trial was undertaken to investigate the effect of organic materials including *neem* cake on the yield and nitrogen uptake by maize crop 'Ganga

5') over the normal package of practices (Gaur and Mathur, 1979). The treatments tested are given in Table 43. Phosphate and potash were applied at 80 kg P_2O_5 /ha as superphosphate and 50 kg K_2O /ha as murate of potash, respectively. All organic materials except farmyard manure were incorporated in soil at 18 tonnes/ha, 15 days prior to sowing and allowed to decompose. In case of straw and neem cake treatment, straw was applied @ 13.5 tonnes/ha and remaining organic matter 4.5 tonnes/ha was added through neem cake. Farmyard manure at 18 tonnes/ha was mixed at the time of sowing. First instalment of nitrogen (50 kg N/ha) at both the depths was added right at the time of incorporation of straw in soil and the remaining 150 kg N was added in split doses. In remaining three treatment, nitrogen was applied in three split doses at 66.6 kg N/ha. Each treatment was replicated 5 times. Irrigation and inter-culture operations were given whenever necessary.

The application of nitrogen at 200 kg N/ha increased the yield of maize crop significantly by 14 q/ha. Application of straw in 0 to 15 cm depth alongwith nitrogen maintained the grain yield obtained with 200 kg N/ha. When straw was mixed in 0 to 7.5 cm depth, a decrease in yield was observed showing nutrient immobilisation due to increased quantum of addition of organic matter in shallow layer. Significantly higher increases in yield were obtained when one-third of the organic matter has neem cake was incorporated alongwith straw. The next best treatment was farmyard manure in combination with nitrogen which also increased the yield significantly. Similar effect was obtained in the case of straw yields. It is interesting to record that maximum nitrogen uptake was obtained in straw + neem cake + nitrogen treatment and the second best was farmyard manure treatment. Straw application in 0 to 15 cm surface soil under tropical conditions can be done without any detrimental effects on crop yields. Neem cake application alongwith straw showed promising results.

Effect of incorporation of organic matter on paddy crop

Organic matter (FYM and straw, 0.5% w/w) was incorporated in sandy loam alluvial soil under field conditions one week before transplanting paddy seedlings (Mukherjee and Gaur, 1980). After one week of decomposition, it was found that application of farmyard manure and wheat straw increased the soil organic carbon by 72 and 79 per cent over control respectively (Table 44). The rate of decomposition of wheat straw was maximum till tillering stage and slower afterwards. The decomposition rate of FYM was faster as compared to wheat straw between tillering and harvesting stage. Application of organic materials increased both humic and humus carbon of soil.

TABLE 44. EFFECT OF INCORPORATION OF ORGANIC MATTER ON DIFFERENT FRACTIONS OF SOIL ORGANIC MATTER UNDER PADDY CROP

Treatment	Before transplanting			At tillering			After harvesting		
	Organic carbon (%)	Humus carbon (%)	Humus content (%)	Organic carbon (%)	Humus carbon (%)	Humus content (%)	Organic carbon (%)	Humus carbon (%)	Humus content (%)
Control	0.435	0.360	0.075	0.510	0.390	0.120	0.495	0.405	0.587
1+0.5% FYM	0.750	0.630	0.120	0.720	0.510	0.210	0.645	0.525	0.760
1+0.5% wheat straw	0.780	0.675	1.105	0.660	0.405	0.195	0.570	0.435	0.670

TABLE 45. EFFECT OF INCORPORATION OF ORGANIC MATTER ON SOIL NITROGEN AND AVAILABLE PHOSPHORUS UNDER PADDY CROP

Treatment	Before transplanting			At tillering			After harvesting		
	Total nitrogen (%)	NH ₄ -N (ppm)	NO ₃ -N (ppm)	Available P (ppm)	Total nitrogen (%)	NH ₄ -N (ppm)	NO ₃ -N (ppm)	Available P (ppm)	Humus content (%)
Control	0.059	17.87	143.87	15.6	0.045	7.49	24.33	16.7	0.038
1+0.5% FYM	0.084	17.94	146.25	16.7	0.064	6.60	34.92	17.8	0.054
1+0.5% wheat straw	0.076	16.04	91.08	11.1	0.056	6.63	35.73	14.4	0.042

TABLE 46. EFFECT OF ORGANIC MATERIALS ON YIELD AND NITROGEN UPTAKE BY PADDY CROP

Treatment	Grain yield (g/plot)	% increase over control	Straw yield (g/plot)	% increase over control	N% in Grain	Uptake of N by grain (g/plot)
Control	666.7	—	831.7	—	0.95	6.3
FYM (0.5%)	941.7	41.2	1048.3	26.0	1.06	10.0
Wheat straw (0.5%)	836.7	25.2	923.3	11.0	0.98	8.2
C.D. at 5% level	76.3	—	78.4	—	—	—

TABLE 47. INFLUENCE OF HUMIC SUBSTANCES ON YIELD OF CROPS

	Per cent increase over control						
	Berseem	Dhaincha	Gram	Soyabean	Moong	Paddy	Wheat
Sodium humate (0.3%)	47.0	22.8	—	—	—	—	27.7
<i>Rhizobium</i>	23.0	18.7	—	—	—	—	—
<i>Azotobacter</i>	—	—	—	—	—	—	4.6
<i>Rhizobium</i> / <i>Azotobacter</i> + humate (0.03%)	52.8	61.5	—	—	—	—	35.4
Humus (0.025%)	—	—	—	—	—	55.7	—
Humus (0.05%)	—	—	32.1	—	—	85.4	—
<i>Rhizobium</i>	—	—	1.0	—	—	—	—
<i>Rhizobium</i> -Humus (0.05%)	—	—	41.0	—	—	—	—
Hydroquinone (10 ppm) sprayed	—	—	—	8.8	33.0	—	97.8
Humate (10 ppm) sprayed	—	—	—	23.2	77.0	—	109.0

RECYCLING OF ORGANIC MATERIALS AS FERTILIZERS

Total nitrogen content in control soil decreased from 0.059 per cent before transplanting to 0.038 at harvest of crop showing a decrease of 35.6 per cent. Due to FYM and straw, appreciable increase in nitrogen content of soil was observed (Table 45). Availability of phosphate was favourably affected by FYM and a very marginal immobilisation of phosphate was observed in straw treated soil.

Farmyard manure significantly increased the grain yield of paddy by 41 per cent and nitrogen uptake by 10 per cent (Table 46). Straw incorporation increased the yield by 25 per cent and uptake of nitrogen by the crop by 8.2 per cent.

Influence of humic substances on crop yields

The effect of humic substance extracted from farmyard manure and other sources was investigated on the growth of plants and microorganisms. The effect on crop yields is summarized in Table 47. Application of sodium humate prepared out of farmyard manure @ 0.03 per cent to soil (w/w) significantly increased the yield of berseem, *dhaincha* and wheat crops by 47.0, 22.8 and 27.7 per cent over their control, respectively (Gaur and Bhardwaj, 1971). Humus (Humic + fulvic fractions) when applied to sandy loam alluvial soil @ 0.025 and 0.05 per cent (w/w) increased the yield of paddy crop by 55.7 and 85.4 per cent. respectively (Mathur and Gaur, 1977). Humus @ 0.05 per cent increased the yield of gram crop by 32.1 per cent.

Spraying of humates even in small dosages (10 ppm) 2 or 3 times during the growth of plants increased the yield of soybean, *moong* and tomato crops by 23.2, 77.0 and 109.0 per cent respectively (Varshney and Gaur, 1974). Similarly hydroquinone sprayed at the same rate increased the yield over control but the response was less as compared to humates.

Beneficial effect of humic substances on the growth of nitrogen-fixing microorganisms has been reported. In these studies (Table 47), it can be observed that the efficiency of *Rhizobium* and *Azotobacter* inoculants was increased due to application of humic materials. The response due to *Azotobacter* inoculation on wheat crop was 5 per cent increase in yield and due to humate it was 27.7 per cent and the combined effect (35.4%) was greater than total of the two. Similar observation was recorded in case of gram and *dhaincha* crops. Nodulation was also improved substantially as recorded in case of gram and *dhaincha*.

VIII. RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

RESPONSE of crops to organic manures depends on several factors such as degree of decomposition and its carbon, nitrogen ratio, soil characteristics, moisture regime of the soil during the period of crop growth, time of its application, etc.

The major organic manures used in this country are the bulky manures, farmyard manure, compost and green manure. Concentrated organic manures such as cakes are not recommended now-a-days and in the past also whatever quantity of cake was used for manuring, was generally on certain crops like sugarcane, fruit crops and some other special crops such as betel-vine. Experimental results on green manure are not included in this bulletin, since there is a separate publication of the ICAR devoted to green manure crops.

Numerous experiments have been carried out in the past at various research stations to study the response of crops to several organic manures. The main results obtained with farmyard manure or compost, oil-cakes and bone-meal as already reported by Garg *et al.* (1971) together with results obtained later on are briefly given here. A good deal of research work on the response of farmyard manure to food crops under varied soil and agro-climatic conditions has been done in "All-India Coordinated Agronomic Research Project". Important data on the use of farmyard manure in respect of experiments on "Manurial Requirements of fixed Crop Rotations" conducted during 1969-70 to 1976-77 have been taken from annual reports of the All-India Coordinated Agronomic Research Project and incorporated in this bulletin.

FARMYARD MANURE AND COMPOST

Rice. Data of 341 experiments on rice crops are available for studying the response of rice to the application of farmyard manure and compost. No distinction could be made between farmyard manure and compost as neither was indicated in the various sources referred to, for the summarization of data. The actual doses tried varied widely from centre to centre. Therefore, in order to summarize the results and give them in a concise form, the responses were standardized at a level of 12.6 tonnes per hectare (5 tonnes per acre). This was done by first fitting suitable response curves relating to the dose applied in those experiments where several doses were

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

tried. Where the amount of manure was specified in terms of nitrogen content, it was assumed, in the absence of definite knowledge on the actual composition of the manure, that the nitrogen percentage was 0.5 for conversion to the quantity of farmyard manure. The results obtained are given in the Table 48 (arranged State-wise). The response to application of 12.6 tonnes per hectare varied from about 100 kg of rice per hectare in Maharashtra and Bihar to 216 kg per hectare in Orissa. The average response based on 341 experiments distributed over 63 research stations in the country was 168 kg per hectare.

Wheat. Results of 210 experiments on irrigated wheat and 71 experiments on unirrigated wheat were studied for finding out the response of wheat to farmyard manure or compost. The responses are given in the Tables 49 and 50 for irrigated and unirrigated wheats respectively. As in rice, the responses were worked out for a standard level since the actual dose varied widely from centre to centre. For irrigated wheat, the dose was taken as 12.6 tonnes per hectare whereas for unirrigated wheat, half of this dose was taken for estimating the response. The actual doses tested varied from 5 to 25 tonnes per hectare on irrigated crop.

Response of irrigated wheat to farmyard manure application at 12.6

TABLE 48. RESPONSE OF RICE TO FARMYARD MANURE AND COMPOST

State	Response to 12.6 tonnes of manure per hectare		
	No. of stations	Number of experiments	Response in kg per hectare
Andhra Pradesh	10	64	194
Bihar	6	14	100
Gujarat	3	11	114
Kerala	3	20	128
Madhya Pradesh	6	31	212
Tamil Nadu	6	51	190
Maharashtra	8	33	99
Karnataka	6	13	168
Orissa	7	44	216
Uttar Pradesh	2	16	139
West Bengal	6	44	195
Average	63	341	168

N.B. Average is taken by weighing the State figures by the area under the crop in the State.

ORGANIC MANURES

**TABLE 49. RESPONSE OF IRRIGATED WHEAT TO FARMYARD
MANURE AND COMPOST**

Response to 12.6 tonnes of manure per hectare			
State	Number of stations	Number of experiments	Response in kg per hectare
Bihar	3	9	295
Delhi	1	21	92
Gujarat	1	1	82
Madhya Pradesh	3	46	259
Maharashtra	2	2	285
Punjab	7	67	213
Rajasthan	6	32	216
Uttar Pradesh	8	32	176
Average	31	210	202

N.B. Average is taken by weighing the State figures by the area under the crop in the State.

**TABLE 50. RESPONSE OF UNIRRIGATED WHEAT TO FARMYARD
MANURE AND COMPOST**

Response to 6.3 tonnes of manure per hectare			
State	Number of stations	Number of experiments	Response in kg per hectare
Gujarat	1	2	87
Madhya Pradesh	7	56	74
Maharashtra	4	10	77
Rajasthan	2	3	140
Average	14	71	85

N.B. Average is taken by weighing the State figures by the area under the crop in the State.

tonnes per hectare ranged as low as 80 to 90 kg per hectare in Gujarat and Delhi to over 250 kg per hectare in Maharashtra, Madhya Pradesh and Bihar. The response of irrigated wheat, on the average, based on 210 experiments distributed over 31 research stations located in different States, was a little over 200 kg per hectare which is somewhat higher than the response obtained with rice. On unirrigated wheat, the response obtained was much lower being only 85 kg per hectare to an application of 6.3 tonnes per hectare. Unirrigated wheat has shown particularly good response in

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

Rajasthan but this is based only on three experiments. In both Madhya Pradesh and Maharashtra, where the number of experiments was large, the responses were about 75 kg per hectare.

Sugarcane. Data of 258 experiments distributed over 8 States and 19 experimental stations were available for examining the response of sugarcane to farmyard manure or compost. The doses tried ranged between 5 to 50 tonnes per hectare. Therefore, the responses were standardized at 25 tonnes per hectare using techniques similar to those described in rice and wheat (Table 51). There is no large variation in the response of sugar-

TABLE 51. RESPONSE OF SUGARCANE TO FARMYARD MANURE AND COMPOST

State	Response to 25.1 tonnes of manure per hectare		
	Number of stations	Number of experiments	Response in tonnes per hectare
Andhra Pradesh	1	10	11.7
Bihar	1	2	3.7
Gujarat	1	1	3.7
Maharashtra	5	132	7.9
Karnataka	2	12	5.9
Punjab	5	30	8.0
Tamil Nadu	2	5	9.8
Uttar Pradesh	2	66	8.4
Average	19	258	

N.B. Average is taken by weighing the State figures by the area under the crop in the State.

cane in different States, the average response being of the order of 8 tonnes of sugarcane for an application of 25 tonnes of farmyard manure. The highest response has been obtained in Andhra Pradesh followed by Tamil Nadu. Only in Bihar and Gujarat, the response was somewhat low. It may be observed that the results for these two States are based on only two and one experiments respectively and, as such, cannot be relied upon much.

Cotton. Data for 71 experiments on irrigated cotton and 294 experiments on unirrigated cotton were available to study the response of cotton to farmyard manure. The doses tried on irrigated cotton ranged between 5 to 25 tonnes per hectare, whereas those on unirrigated cotton between 5 to 13 tonnes. The responses were standardized at 12.6 and 6.3 tonnes per hectare of farmyard manure on irrigated and unirrigated cottons res-

ORGANIC MANURES

**TABLE 52. RESPONSE OF IRRIGATED COTTON TO FARMYARD
MANURE AND COMPOST**

Response to 12.6 tonnes of manure per hectare			
State	Number of stations	Number of experiments	Response (lint) in kg per hectare
Karnataka	2	16	80.9
Punjab	5	26	49.8
Tamil Nadu		5	96.1
Uttar Pradesh	2	24	48.9
Average	10	71	56.4

N.B. Average is taken by weighing the State figures by the area under the crop in the State.

**TABLE 53. RESPONSE OF UNIRRIGATED COTTON TO FARMYARD
MANURE AND COMPOST**

Response to 6.3 tonnes of manure per hectare			
State	Number of stations	Number of experiments	Response (lint) in kg per hectare
Andhra Pradesh	2	28	12.8
Gujarat	4	57	11.8
Madhya Pradesh	5	42	22.3
Maharashtra	10	113	15.9
Karnataka	4	54	20.2
Average	25	294	16.2

N.B. Average is taken by weighing the State figures by the area under the crop in the State.

pectively (Tables 52-53). The response of irrigated cotton shows large variation, it being nearly double in the southern States as compared with Punjab and Uttar Pradesh, in the north. Under unirrigated conditions, the response was somewhat poor ranging between 12 to 22 kg of lint per hectare.

Potato. The results of more than 30 experiments conducted on potato are given in Table 54. As in other crops, there has been considerable variation in the quantity of farmyard manure used. Generally, there has been an increase in yield with the application of farmyard manure varying

TABLE 54. RESPONSE OF POTATO TO FARMYARD MANURE AND COMPOST

State	Station	Year(s)	No. of Experi- ments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentages of control	Remarks (Irrigated (Unirrigated)
Himachal Pradesh	Shillaroo	1951-53	7	Control F.Y.M. 36.88 tonnes/ha	15437	3894	1332	25.2	Unirrigated
Himachal Pradesh	Shillaroo	1953	1	Control F.Y.M. 9.21 tonnes/ha F.Y.M. 18.42 tonnes/ha F.Y.M. 36.85 tonnes/ha	8409 — —	8589 9239 13178	— 1213 —	102.1 109.9 156.7	”
Madhya Pradesh	Chhindwara	1948-51	2	Control T.C. at 37.66 tonnes/ha	8159	354	860	4.3	Irrigated
Orissa	Sambalpur	1955-56	2	Control F.Y.M. 8.96 tonnes/ha	2392	381	1384	15.9	Irrigated
Punjab	Jullundur	1949-52	3	Control F.Y.M. 22.42 tonnes/ha	6437	235	236	3.7	Irrigated
Uttar Pradesh	Farrukhabad	1955-57	3	Control F.Y.M. 22.42 tonnes/ha	15892	536	710	3.4	Irrigated
Uttar Pradesh	Lucknow	1951	1	Control F.Y.M. 26.89 tonnes/ha	7806	2396	1781	30.7	Irrigated
Uttar Pradesh	Kanpur	1952-66	7	Control F.Y.M. 22.42 tonnes/ha	16820	2439	2200	14.5	Irrigated

TABLE 54 (Contd)

State	Station	Year(s)	No. of Experi- ments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentage of control	Remarks (Irrigated) (Unirrigated)
Uttar Pradesh	Kanpur	1955	1	Control	11308	1502	987	13.3	Information regarding irrigation status not available
				F.Y.M. 3892 tonnes/ha					
Uttar Pradesh	Kanpur	1953	1	Control F.Y.M. 28.02 tonnes/ha	24821	764	1568	3.1	Irrigated

TABLE 55. RESPONSE OF SWEET-POTATO TO FARMYARD MANURE AND COMPOST

State	Station	Year(s)	No. of Experi- ments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentage of control	Remarks
Karnataka	Mangalore	1951-56	6	Control F.Y.M. 11.21 tonnes/ha	9007	2757	298	30.6	Unirrigated
Tamil Nadu	Coimbatore	1951-53	3	Control F.Y.M. 11.21 tonnes/ha	7426	1084	261	14.6	Irrigated

TABLE 56. RESPONSE OF TAPIOCA TO FARMYARD MANURE AND COMPOST

State	Station	Year(s)	No. of Experi-ments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentage of control	Remarks
Tamil Nadu	Coimbatore	1951-53	3	Control F.Y.M. 11.21 tonnes/ha	3872	455	254	11.8	Irrigated

TABLE 57. RESPONSE OF ONION TO FARMYARD MANURE AND COMPOST

State	Station	Year(s)	No. of Experi-ments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentage of control	Remarks
Maharashtra	Niphad	1961-63	2	Control F.Y.M. 11.21 tonnes/ha	32062	2980	1190	9.3	Information regarding irriga- tion status not available
				F.Y.M. 22.42 tonnes/ha		5407		16.9	

TABLE 58. RESPONSE OF GARLIC TO FARMYARD MANURE AND COMPOST

State	Station	Year(s)	No. of Experi-ments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentage of control	Remarks
Uttar Pradesh	Lucknow	1950	1	Control F.Y.M. 22.42 tonnes/ha	3384	508	191	15.0	Irrigated

TABLE 59. RESPONSE OF CHILLIES (DRY) TO FARMYARD MANURE AND COMPOST

State	Station	Year(s)	No. of Experiments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentage of control	Remarks
Kerala	Taliparanha	1948-50	4	Control F.Y.M. 12.55 tonnes/ha	693	616	326	889	Unirrigated
Andhra Pradesh	Lam	1945-48	8	Control F.Y.M. 11.20	462	74	29	16.0	Information regarding irrigation status is not available
Andhra Pradesh	Lam	1950	1	Control F.Y.M. 26.89 tonnes/ha	633	235	97	37.1	"
Andhra Pradesh	Lam	1955-57	3	Control F.Y.M. 8.96 tonnes/ha F.Y.M. 13.46 tonnes/ha F.Y.M. 17.93 tonnes/ha	888	305	101	34.3	Unirrigated
						354		39.9	
						451		50.8	

TABLE 60. RESPONSE OF *Bhindi* TO FARMYARD MANURE AND COMPOST

State	Station	Year(s)	No. of Experiments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentage of control	Remarks
Maharashtra	Poona	1961-63	2	Control F.Y.M. 11.21 tonnes/ha F.Y.M. 22.42 tonnes/ha	6558	235	269	3.6	Information on irrigation status not available
						357		5.4	Heavy rainfall is reported

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

TABLE 61. RESPONSE OF TOMATO TO FARMYARD MANURE AND COMPOST

State	Station	Year(s)	No. of Experi-ments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentage of control	Remarks
Maharashtra	Poona	1960-63	3	Control	13128	175	304	1.3	Information on irrigation status is not available
				F.Y.M. 11.21 tonnes/ha F.Y.M. 22.42 tonnes/ha		866		6.6	Heavy rainfall is reported

TABLE 62. RESPONSE OF BRINJAL TO FARMYARD MANURE AND COMPOST

State	Station	Year(s)	No. of Experi-ments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentage of control	Remarks
Maharashtra	Poona	1956-59	4	Control	31204	660	3906	2.1	Unirrigated
				F.Y.M. 12.55 tonnes/ha F.Y.M. 25.11 tonnes/ha		370		1.1	—
Uttar Pradesh	Lucknow	1949	1	Control	15538	247		1.6	Irrigated
				F.Y.M. 7.83 tonnes/ha F.Y.M. 15.69 tonnes/ha		710	2234	4.6	—
				F.Y.M. 31.38 tonnes/ha		148		0.9	—

TABLE 63. RESPONSE OF SPINACH TO FARMYARD MANURE AND COMPOST

State	Station	Year(s)	No. of Experi-ments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentage of control	Remarks
Uttar Pradesh	Lucknow	1953	1	Control	559	163		29.2	
				F.Y.M. 6.72 tonnes/ha					
				F.Y.M. 8.96 tonnes/ha		308	63	55.0	Irrigated
				F.Y.M. 11.20 tonnes/ha		524		93.7	

TABLE 64. RESPONSE OF *Methi* TO FARMYARD MANURE AND COMPOST

State	Station	Year(s)	No. of Experi-ments	Treatments	Control/ yield (kg/ha)	Response (kg/ha)	S.E. of response (kg/ha)	Response as percentage of control	Remarks
Maharashtra	Poona	1961-62	1	Control	3542	—118	220	—3.3	It is not known whether the crop was irrigated or not. But during crop season heavy rainfall was reported.
				F.Y.M. 5.60 tonnes/ha F.Y.M. 11.20 tonnes/ha		348	2	9.8	
Poona	1960-61	1		Control	5550	428	430	7.7	
				F.Y.M. 12.55 tonnes/ha F.Y.M. 25.11 tonnes/ha		588		10.6	

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

TABLE 65. RESPONSE OF SUGARCANE TO OIL-CAKES

State	Station	Year(s)	No. of Experi-ments	Treatments	Control/ yield (cane) in tonnes/ha	Response (cane) in tonnes/ha		S.E. of response in tonnes/ha	Remarks
						Cake alone	A/S: cake		
Andhra Pradesh	Ankapalle	1951-59	9	Control	49.48	42.79	47.06	1.96	A/S : cake in the ratio of 1:0
	Ankapalle	1950-51	2	Control	96.36	N.A.	18.56	4.87	A/S : cake in the ratio of 2:1
				112.1 kg N/ha			12.38		
				224.2 kg N/ha			17.20		
Bihar	Rudur	1957-59	3	Control	15.27	58.12	66.03	5.05	A/S : cake in the ratio of 1:0
	Dehri-on Sone	1954	2	Control	39.52	6.12	N.A.	3.49	A/S : cake in the ratio of 1:0
				44.8 kg N/ha		8.61	0.65	2.74	A/S : cake in the ratio of 1:0
	Patna	1956-57	2	Control	28.52	3.67	7.71	2.56	A/S: cake in the ratio of 1 : 1
Maharashtra		1954-56	4	Control	42.63	6.61	—	4.67	
	Warisaligang	1954-56	3	134.5 kg N/ha	89.71	4.94	N.A.	2.84	A/S: cake in the ratio of 1 : 0
				Control		7.15	20.04	5.32	A/S: cake in the ratio of 1 : 0
	Padegaon	1954-59	6	Control	61.91	26.72	2.21	N.A.	A/S: cake in the ratio of 1 : 0
Uttar Pradesh	Anandnagar	1958	1	336.3 kg N/ha	58.32	0.33	2.31	2.33	A/S: cake in the ratio of 1 : 0
	Bhojapur	1958	1	Control	35.50	8.69	10.36	2.54	A/S: cake in the ratio of 1 : 0
	Etawah	1957-59	3	Control	44.67	2.05	6.36	6.95	
	Golgokuranath	1959	1	Control	45.29	2.76	0.78		
Uttar Pradesh	Khadda	1958	1	67.2 kg N/ha	22.67	2.06			
				Control					

ORGANIC MANURES

TABLE 65 (Contd)

State	Station	Year(s)	No. of Experiments	Treatments	Control/ yield (cane) in tonnes/ha	Response (cane) in tonnes/ha	S.E. of response in tonnes/ha	Remarks
Uttar Pradesh	Kunraghat	1956-58	3	Control	34.85	5.90	4.89	"
	Masodha	1958	1	Control	52.17	27.62	5.32	"
	Modinagar	1955	1	Control	39.99	0.70		
				44.8 kg N/ha		—7.48		
				89.6 kg N/ha		—1.99		
				134.5 kg N/ha				
	Muzaffarnagar	1954-59	8	Control	43.99	20.89		A/S: cake in the ratio of 1:0
				134.5 kg N/ha				
		1956-58	3	Control	50.87	1.96		"
	Neeli	1959	1	Control	41.50	11.25	6.40	"
	Rampur	1959	1	Control	30.81	5.62		"
				67.2 kg N/ha		13.56	5.65	
	Raya	1959	1	Control	52.98	7.38	0.40	A/S: cake in the ratio of 1:0
	Saini	1959	1	Control	58.55	6.68	15.77	"
	Seohara	1959	1	Control	58.20	2.11	4.57	"
	Shahjahanpur	1954-59	10	Control	61.09	8.53	1.28	"
				67.2 kg N/ha		—8.34		
			1	Control	53.93	16.39		
	Varanasi	1957-59	3	Control	44.57	0.19	2.41	"
				112.1 kg N/ha			3.34	
	Haldwani	1959	1	Control	42.98	2.21	1.76	"
				67.2 kg N/ha				

TABLE 66. YIELD RESPONSE OF SUGARCANE TO DIFFERENT DOSES OF AMMONIUM SULPHATE AND GROUNDNUT-CAKE

State	Station	Year(s)	No. of Experiments	Treatments Dose in 'Ratio kg/ha' of G.N.C. A/s	Yield in tonnes/ha	S.E. of difference of means in tonnes/ha
Maharashtra	Padegaon	1954-59	8	336	97.26	2.39
				1:0	76.40	
				0:1	95.73	
				1:1	93.10	
				2:1	89.91	
				1:2		

TABLE 67. RESPONSE OF UNIRRIGATED COTTON TO OIL-CAKES

State	Station	Year(s)	No. of Experiments	Treatments	Contrl/ yield (lint) in kg/ha	Response (lint) in kg/ha	S.E. of response in kg/ha	Remarks
Andhra Pradesh	Mudhol	1948-49	2	(A) Control	62	Cake alone 30	4.2	
				22.4 kg N/ha				
	Warangal	1948	2	44.8 kg N/ha	142	44	N.A.	
				Control				
Madhya Pradesh	Amdaha	1955	1	22.4 kg N/ha	42	50	109	15.5
				44.8 kg N/ha				
	Indore	1954-55	2	67.2 kg N/ha	58	102	144	
				Control				
Karnataka	Dharwar	1954	1	44.8 kg N/ha	243	21	8	8.1
				Control				
	Hogari	1954-58	5	22.4 kg N/ha	125	—4	N.A.	5.5
				44.8 kg N/ha				
Punjab	Rauni	1954	1	Control	381	34	32	14.3
				33.6 kg N/ha (B)				
				28.0 kg N/ha		8	13	4.5
				Control				
				28.0 kg N/ha		63	A/S alone 64	44.9
				Control				

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

from 3 to 4 per cent to as much as 30 per cent of the control yield.

Other crops. Experimental results on the effect of farmyard manure on some crops of vegetables and chillies are also available (Tables 55-64). Application of farmyard manure has resulted in a significant increase in the yield of chillies. The response varied from 16 to 89 per cent. Results of similar experiments on *methi*, onion, sweet-potato, tomato and tapioca are also given. It will be seen that the response showed wide variation. But in general, there has been a positive response, particularly to sweet-potato, tapioca and onion.

OIL-CAKES

The principal oil-cakes used for manuring in India are groundnut-cakes and mustard-cakes. As already mentioned, oil-cake as manure for food-grains is not being encouraged for various reasons. Therefore, in the present bulletin, the results of experiments with oil-cakes only on cash crops such as sugarcane and cotton are presented.

Sugarcane. Results of more than 70 field experiments conducted on sugarcane in different States are available. These experiments were generally conducted to compare the performance of oil-cakes with ammonium sulphate, the traditional fertilizer (Tables 65-66).

In Andhra Pradesh, at the main Sugarcane Station, Anakapalle, trials conducted with groundnut-cake gave high response which was of the same order as for ammonium sulphate applied on equal nitrogen basis. At Rudrur in Andhra Pradesh also, the response to groundnut-cake was very high, but not higher than that of ammonium sulphate. At Padegaon in Maharashtra, the response to oil-cakes was higher than that of ammonium sulphate. In Bihar, the trials were conducted with castor-cakes. The response to cakes applied at the rate of 90 kg per hectare was 6.57 tonnes per hectare. In Uttar Pradesh, groundnut-cake was generally used. The responses were not particularly high, the average response to 57 kg per hectare over 14 centres being equal to 6.01 tonnes per hectare. The results of some trials with varying proportions of cakes and ammonium sulphate at different levels of nitrogen were also available in Maharashtra. The data generally showed that with the increase in the proportion of groundnut-cake, the response also increases.

A number of experiments comparing nitrogen application with varying proportions of groundnut-cake and ammonium sulphate were conducted in Maharashtra (Table 66).

Groundnut-cake alone has given a higher response. The yield figures corresponding to other ratios of groundnut-cake and ammonium sulphate also show that the response is higher with a higher proportion of cakes in

ORGANIC MANURES

the mixture, indicating that groundnut-cake is superior to ammonium sulphate.

Cotton. Data from 13 experiments on cotton were available to study the effect of application of groundnut-cake. The responses on irrigated cotton showed large variation (Table 67), the best response having been obtained at Warrangal in Andhra Pradesh. The responses in all the cases were not significantly different from those to ammonium sulphate applied at the same level.

LONG-TERM EFFECT OF ORGANIC MANURES

The knowledge on the effect of continuous application of organic and inorganic fertilizers on crop production and soil fertility is of considerable importance in formulating a sound and long-term manurial policy. We have earlier given the results of the direct effect of organic manures. Similar knowledge on the long-term effect has to be obtained from the results of carefully conducted manurial trials. Such long-term experiments have been very few in this country. Results of some of the long-term experiments are given below:

Rice. In West Bengal, long-term experiments with and without application of farmyard manure and with different fertilizer doses were conducted at Chinsura, Berhampore and Suri farms. At Chinsura and Suri farms, experiments were started in 1948-49 and at Berhampore in 1949-50. The soil of Chinsura farm is typical Ganga low-land and is nearly neutral in reaction (pH 6.8). The soil of Suri farm is of lateritic origin and is acidic in reaction (pH 5.5). The soil at Berhampore is sandy-loam and alkaline in reaction (pH 7.7).

The response of rice to farmyard manure and trend of yield over the entire period of experimentation as compared with the application of fertilizers are given in Tables 68 to 70. Application of farmyard manure at Chinsura did not increase the yield, but at Suri and Berhampore there was a significant increase with the application of farmyard manure alone at the rate of 9 tonnes per hectare. Further, a study of trend in yield as indicated by the regression of yield over the years showed that plots treated with farmyard manure at Suri and Berhampore farms gained annually by 90 and 156 kg per hectare, respectively over the plots to which farmyard manure was not applied.

At the Central Rice Research Institute, Cuttack, experiments were conducted from 1949-50 to study the long-term effect of compost application with and without nitrogen. One experiment was conducted with combinations 0, 22.4, 44.8, 67.2 and 89.6 kg of nitrogen with and without compost at 9.2 tonnes per hectare. In another experiment, three levels

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

TABLE 68. RESPONSE OF RICE TO FARMYARD MANURE AND REGRESSION OF YIELD OVER YEARS (KG/HA)

Station: Chinsurah		State: West Bengal			Period: 1948-49 to 1960-61		
Soil characteristics	Levels of N in kg/ha	Mean cumulative yield			Linear regression of yield over years		
		F.Y.M. Levels			F.Y.M. Levels		
		0	9220	Average	0	9220	Average
Alluvium neutral in reaction	0	1430	1470	1450	43.0	45.8	44.4
	33.6	1540	1550	1545	31.4	31.9	31.7
	67.2	1440	1370	1405	31.2	17.1	24.1
	100.8	1290	1220	1255	21.1	13.2	17.2
	133.4	1190	1150	1170	17.2	13.0	15.1
Average		1378	1352	1365	28.7	24.2	26.5
S.E. of difference				S.E. of difference			
(i) between N means = 20.0				(i) between N means = 4.09			
(ii) between F.Y.M. means = 9.0				(ii) between F.Y.M. means = 1.91			

TABLE 69. RESPONSE OF RICE TO FARMYARD MANURE AND REGRESSION OF YIELD OVER YEARS (KG/HA)

Station: Suri		State: West Bengal			Period: 1948-49 to 1960-61		
Soil characteristics	Levels of N in kg/ha	Mean cumulative yield			Linear regression of yield over years		
		F.Y.M. Levels			F.Y.M. Levels		
		0	9220	Average	0	9220	Average
Lateritic acidic	0	1620	2020	1820	2.9	18.6	10.7
	33.6	1970	2150	2060	—16.7	—3.9	—10.3
	67.2	2020	2020	2020	—29.1	—28.8	—29.0
	Average	1870	2063	1967	—14.3	—4.7	—9.5
S.E. of difference				S.E. of difference			
(i) between N means = 35.0				(i) between N means = 5.39			
(ii) between F.Y.M. means = 29.0				(ii) between F.Y.M. means = 4.40			

ORGANIC MANURES

TABLE 70. RESPONSE OF RICE TO FARMYARD MANURE
AND REGRESSION OF YIELD OVER YEARS (KG/HA)

Station: Berhampore		State: West Bengal			Period: 1948-49 to 1960-61		
Soil characteristics	Levels of N (kg/ha)	Mean cumulative yield			Linear regression of yield over years		
		F.Y.M			F.Y.M.		
		0	9220	Average	0	9220	Average
Laterite, sandy-loam alkaline in reaction	0	20	530	475	—24.7	— 7.6	—16.1
	33.6	640	750	695	—24.7	— 6.5	—15.6
	67.2	790	890	840	—20.9	—14.2	—17.6
	100.8	830	930	880	—39.7	—17.4	—28.6
	133.4	740	920	830	—28.5	—14.8	—21.7
Average		684	804	744	—27.7	—12.1	—19.9
S.E. of difference				S.E. of difference			
(i) between N means = 33.0				(i) between N means = 4.4			
(ii) between F.Y.M. means = 11.0				(ii) between F.Y.M. means = 2.6			

each of nitrogen, phosphorus and potash were tried in combination with green manure, groundnut cake and farmyard manure applied at the rate of supplying 22.4 kg per hectare nitrogen. A third experiment was conducted at the same centre, with three levels of nitrogen and three levels of lime. After the first four years, the experiment was modified to include compost as one of the factors (Tables 71-74). In the experiment No. 1, compost applied alongwith nitrogen up to 22.4 kg per hectare has shown significant response. Plots in which compost was applied showed gain in yield for years as compared with the plots in which no farmyard manure was applied. In the experiment with different organic manures, fertilizers and application of compost has not shown a significant increase in yield either in the absence of other nitrogenous fertilizers or when nitrogen was applied. There were also no significant differences in the trend in yield but showed that compost-treated plots gained at the rate of 17 kg per hectare annually over plots receiving no compost.

Sahu and Nayak (1971) reported the results of a long-term experiments on "Soil Fertility Investigations" conducted for ten years from 1956 to 1965. Investigations were carried out on a sandy loam lateritic soil of Bhubaneswar, Orissa to study the effect of continuous application of ammonium sulphate and organic manures, viz. FYM, green manure and groundnut cake (GNC)

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

TABLE 71. RESPONSE OF RICE TO COMPOST AND
REGRESSION OF YIELD OVER YEARS (KG/HA)

Station: Cuttack		State: Orissa			Period : 1949-50 to 1962-63		
Soil characteristics	Levels of N (kg/ha)	Mean cumulative yield of compost			Linear regression of yield over years of compost		
		0	9220	Average	0	9220	Average]
N.A.	0	14.00	1720	1560	— 2.3	8.7	3.2
	22.4	16.30	1920	1775	2.7	3.3	3.0
	44.8	18.60	18.50	18.55	0.0	— 9.1	— 4.5
	67.2	1890	1710	1800	7.0	44	5.7
	100.8	1780	14.20	1600	14.7	13.0	13.9
Average		1712	1724	1718	4.4	4.1	4.2
S.E. of difference				S.E. of difference			
(i) between N means = 28.0				(i) between N means = 7.6			
(ii) between compost means = 27.0				(ii) between compost means = 2.6			

singly as well as in combination on the yield of lowland rice crop. Grain yield data (mean of 10 years) have been given in Table 75 which shows that the highest grain yield of 2,667 kg/ha was obtained with basal dressing of FYM to supply 45 kg N/ha together with 45 kg N/ha as ammonium sulphate the increase over control yielding 2,147 kg/ha being 520 kg/ha.

Padalia (1975) reported the results of a long-term experiment on a high-yielding variety of rice carried out at Central Rice Research Institute, Cuttack for seven years from 1967 to 1973. Two levels of compost to supply 0 and 80 kg N per ha were tried with and without inorganic nitrogen. The

TABLE 72. RESPONSE YIELD OF RICE TO ORGANIC MANURES (KG/HA)

Station: Cuttack		State: Orissa		Period: 1949-50 to 1953-54	
Level of N9 (kg/ha)	Organic Manures		Groundnut-cake	Compost	Average
	No manure	Green manure			
0	1448	1615	1607	1533	1551
22.4	1553	1634	1578	1646	1603
44.8	1635	1644	1469	1692	1641

S.E. of difference
(i) between N means = 10.0
(ii) between manure means = 91.0

ORGANIC MANURES

TABLE 73. LINEAR REGRESSION OF YIELD OF RICE OVER YEARS (KG/HA)

Station: Cuttack		State: Orissa		Period: 1949-50 to 1953-54	
Levels of N (kg /ha)	Organic Manures		Groundnut-cake	Compost	Average
	No manure	Green manure			
0	13.41	8.34	—65.28	33.20	— 2.58
22.4	—16.53	21.23	—63.58	15.37	—10.88
44.8	—10.56	9.28	—62.88	23.07	—10.27
Average	—4.56	12.95	—63.92	23.88	—7.91

S.E. of difference

(i) between N means = 21.32

(ii) between two manure means = 33.72

doses of inorganic nitrogen from ammonium sulphate were 0, 40, 80, 120 and 160 kg N per ha. Seven years mean grain yield data of rice crop, have been given in Table 76. Response due to compost alone to supply 80 kg N/ha was 408 kg/ha of grains, the increase over control being 9.9 per cent. Application of compost alone was found to be inferior to ammonium sulphate at similar rate of application. However, application of compost at the rate of 80 kg N/ha in combination with ammonium sulphate to supply total quantity of 120 or 160 kg N/ha gave higher yields than the

TABLE 74. RESPONSE OF RICE TO COMPOST AND REGRESSION OF YIELD OVER YEARS (KG/HA)

Station: Cuttack		State : Orissa		Period: 1952-53 to 1962:63			
Soil characteristics	Levels of N (kg/ha)	Mean cumulative yield			Linear regression of yield on years		
		Compost Average			Compost	Average	
N.A.	0	0	9220		0	9220	
	0	13.60	1780	1570	—15.6	14.5	—15.1
	22.4	1700	1990	1845	—43.8	—22.5	—33.1
	44.8	1910	2050	1970	—47.6	—17.3	—32.5
Average		1657	1933	1795	—35.7	—18.1	—26.9
S.E. of difference				S.E. of difference			
(i) between N means = 25.0				(i) between N means = 3.8			
(ii) between compost means = 31.0				(ii) between compost means = 1.9			

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

TABLE 75. GRAIN YIELD OF RICE CROP DUE TO ORGANIC AND INORGANIC MANURES (KG/HA)

Station : Bhubaneswar		State : Orissa		Period: 1956 to 1965	
Levels of N (kg/ha)	Yield without basal dressing	Yield with basal dressing (45 kg N/ha)			Mean
		F.Y.M.	G.M.	G.N.C.	
0	2147	2443	2511	2402	2376
22.5	2345	2468	2400	2364	2394
45.0	2361	2667	2496	2390	2479
67.5	2411	2396	2267	2179	2313
90.0	2231	2280	2021	2200	2183
Mean	2299	2451	2339	2307	

corresponding levels of nitrogen in the form of ammonium sulphate.

Sugarcane. Apart from the long-term experiments in rice, results of a few experiments on sugarcane are also available. Long-term experiments on sugarcane were conducted at Padegaon, Kopergaon, Deolali and Akluj. At Padegaon, the experiment was started in the year 1939-40 on a three-course rotation of sugarcane, *jowar* and groundnut. The treatment consisted of combinations of two levels of compost with the six treatments made up of a control and 336 kg of nitrogen supplied by ammonium sulphate, groundnut-cake and mixtures of the two in three fixed rotations. Compost

TABLE 76. GRAIN YIELD OF RICE CROP DUE TO ORGANIC AND INORGANIC MANURES

Station : Cuttack		State : Orissa		Period : 1967 to 1973	
Levels of N (kg/ha)	Grain yield kg/ha		Increase due to compost in kg/ha		
	Without compost	With compost providing 80 kg N/ha			
0	4132	4540	408		
40	4568	4972	404		
80	4882	5037	155		
120	4844	4831	decrease		
160	4769	4782	13		
Mean	4639	4832			

ORGANIC MANURES

TABLE 77. RESPONSE OF SUGARCANE TO ORGANIC MANURES AND REGRESSION OF YIELD OVER YEARS (TONNES/HA)

Station: Padegaon	State: Maharashtra			Period: 1940-41 to 1955-56		
Treatments	Mean yield			Linear regression of yield over years		
	No Compost	Compost	Average	No Compost	Compost	Average
Control	30.8	39.2	35.0	— 4.44	— 1.75	— 2.09
Groundnut-cake	102.7	111.3	107.0	— 5.86	— 8.16	— 7.01
Ammonium sulphate	61.4	86.2	73.8	—12.27	—10.49	—11.38
A/S: G.N.C. (1:1)	95.6	107.0	101.3	8.86	— 7.81	0.52
A/S: G.N.C. (1:2)	96.9	112.1	104.5	— 9.94	— 8.80	— 9.37
A/S: G.N.C. (2:1)	81.2	102.3	91.8	— 9.53	— 6.12	— 7.82
Average	78.1	93.0	85.6	— 5.53	— 7.19	— 6.36
S.E. of difference			S.E. of difference			
(i) between compost means = 1.66			(i) between compost means = 0.70			
(ii) between treatment means = 2.88			(ii) between treatment means = 1.22			

TABLE 78. RESPONSE OF SUGARCANE TO ORGANIC MANURES AND REGRESSION OF YIELD OVER YEARS (TONNES/HA)

Station: Padegaon	State: Maharashtra			Period: 1941-42 to 1956-57		
Treatments	Mean yield			Linear regression of yield over years		
	No Compost	Compost	Average	No Compost	Compost	Average
Control	37.2	43.9	40.5	1.98	5.97	3.97
Groundnut-cake	105.8	124.7	115.2	—8.46	—2.78	—5.62
Ammonium sulphate	72.0	100.4	86.2	—7.70	—4.01	—5.85
A/S: G.N.C. (1:1)	96.1	155.8	105.9	—6.78	—6.02	—6.40
A/S: G.N.C. (1:2)	104.2	123.0	113.6	—7.46	—0.60	—4.03
A/S: G.N.C. (2:1)	86.2	115.0	99.6	—8.97	—1.15	—5.06
Average	83.6	103.5	93.5	—6.23	—1.23	—3.83
S.E. of difference			S.E. of difference			
(i) between compost means = 2.45			(i) between compost means = 0.73			
(ii) between treatment means = 4.24			(ii) between treatment means = 1.26			

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

was applied at the rate of 25 tonnes per hectare, which contained approximately 135 kg N, 135 kg P_2O_5 and 720 kg K_2O . The experiment was modified in the year 1951-52. The 'no compost' plots were divided into two parts. To one of these, an additional treatment of nitrogen, phosphate and potash mixture in the form of commercial fertilizers and equivalent to a dose of 25 tonnes of compost per hectare was applied. The experiment was again modified in 1954-55 when the compost plots were also subdivided in two and the nitrogen, phosphate and potash mixtures were applied as above (Tables 77-78). Significant responses to the application of nitrogen and compost were obtained. The response was significantly higher with groundnut-cake as compared with ammonium sulphate. The results of plots treated with combinations of two fertilizers in different ratios also indicated the superiority of groundnut-cake. The response to nitrogen in the form of ammonium sulphate was enhanced when this fertilizer was applied in combination with compost. Considering the rates of change in yield with years, it is seen that there was a deterioration in the yield of all plots, but the application of compost resulted in a pronounced reduction in the rate of deterioration in nitrogen-treated plots. Considering the results for the first four crops and that for the entire period, it will be seen that the application of compost was effective in reducing deterioration in the soil fertility resulting from the continued application of nitrogen for short period but this could not, however, be maintained for a longer period.

The long-term experiments at Kopergaon, Deolali and Akluj commenced on identical plans from the year 1941-42. The three-course rotation of sugarcane, *jowar* and groundnut was adopted. The experiment consisted of three series corresponding to each of the three crop phases of the rotation.

The yield of sugarcane became available from 1941-42. The experiment was discontinued after 1949-50. The results pertaining to the sugarcane crop are briefly discussed below:

The experimental treatment consisted of all combinations of two levels of compost with four treatments made up of 336 kg nitrogen per hectare, supplied by groundnut-cake and mixture of groundnut-cake and ammonium sulphate in three fixed ratios. Compost was applied at 20 cart-loads per hectare.

At Kopergaon (Table 79), plots treated with combinations of ammonium sulphate and groundnut-cake indicated superiority of groundnut-cake over ammonium sulphate. Significant response to the application of compost was also obtained. The rate of change of yield with years showed a negative trend in the yields of plots under all the treatments. Application of compost did not bring in a significant reduction in the rate of deterioration.

ORGANIC MANURES

TABLE 79. RESPONSE OF SUGARCANE TO ORGANIC MANURES AND REGRESSION OF YIELD OVER YEARS (TONNES/HA)

Station: Kopergaon	State: Maharashtra			Period: 1941-42 to 1949-50		
Treatments	Mean yield			Linear regression of yield over years		
	No compost	Compost	Average	No compost	Compost	Average
Groundnut-cake	106.5	115.9	111.2	—6.28	—7.56	—6.98
A/S: G.N.C. (1:1)	100.3	113.2	106.7	—6.09	—8.21	—7.15
A/S: G.N.C. (1:2)	99.0	115.3	107.1	—14.18	—11.48	—12.83
A/S: G.N.C. (2:1)	91.1	108.4	99.7	—11.12	—6.35	—8.73
S.E. difference			S.E. of difference			
(i) between two compost means = 1.64			(i) between two compost means = 1.59			
(ii) between treatment means = 2.32			(ii) between two treatment means = 2.25			

At Deolali (Table 80), groundnut-cake alone showed significantly higher response as compared with plots treated with combinations of oil-cakes and ammonium sulphate. It is interesting to note that in the plots treated with mixture of ammonium sulphate and groundnut-cakes, the yields were higher with higher content of groundnut-cakes. Application of compost also resulted in a significant increase in yields. As in Kopergaon, there was a significant deterioration in the yield of all plots. Addition of compost in all plots except in those treated with groundnut-cake alone resulted in significant reduction in the rate of deterioration. Even in the latter plots, there was a reduction in the rate of deterioration but it was not statistically significant.

As at the two centres, Kopergaon and Deolali, at Akluj (Table 81) also, plots treated with groundnut-cake alone or with higher percentage of groundnut-cake in the mixture gave higher response. Application of compost significantly increased the sugarcane yield. Although there was a negative trend in the rate of response under different treatments with years, application of compost had a beneficial effect in reducing the rate of deterioration.

The results of the treatments at the three centres, therefore, are generally quite similar. In all the cases, responses were higher when the percentage of nitrogen in the form of groundnut-cake was higher in the cake-sulphate mixture. Estimation of the difference in the effect of groundnut-cake and ammonium sulphate made from these experiments gave the following results:

As can be seen, the difference between the true effect of nutrients applied

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

MEAN DIFFERENCE BETWEEN TRUE EFFECTS OF GROUNDNUT-CAKE AND AMMONIUM SULPHATE IN TONNES PER HECTARE

Centre	Mean difference	S.E. of mean difference
Kopergaon	15.4	3.32
Deolali	22.7	3.23
Akluj	35.5	5.97

in the form of groundnut-cake and ammonium sulphate is statistically significant at all the three centres.

A long-term experiment to determine the relative value of organic and inorganic manures applied to sugarcane crop was conducted for 13 years from 1949-50 to 1961-62 at Sugarcane Research Sub-station, Muzaffarnagar, U.P. and the results were published by Ambika Singh (1964). The trial was conducted in two adjacent fields in alternate years with a sugarcane-fallow-sugarcane rotation so that a crop of sugarcane was available every year. So in one field, sugarcane crop was taken for 7 years from 1949-50 to

TABLE 80. RESPONSE OF SUGARCANE TO ORGANIC MANURES AND REGRESSION OF YIELD OVER YEARS (TONNES/HA)

Station: Deolali		State: Maharashtra		Period : 1941-42 to 1949-50		
Treatments		Mean yield		Linear regression of yield over years		
		No compost	Compost	Average	No compost	Compost
				Average		
Groundnut-cake		89.6	98.5	94.0	—21.05	—16.71
A/S: G.N.C. (1:1)		76.7	86.0	81.3	—23.60	—12.09
A/S: G.N.C. (1:2)		83.7	88.4	86.0	—21.54	—13.40
A/S: G.N.C. (2:1)		72.5	86.6	79.5	—17.54	— 8.38
Average		80.6	89.9	85.2	—20.93	—12.64
S.E. of difference				S.E. of difference		
(i) between compost means = 2.94				(i) between compost means = 2.80		
(ii) between treatment means = 4.16				(ii) between treatment means = 3.94		

1961-62 and in the other field for 6 years from 1950-51 to 1960-61. The experiment consisted of seven treatments, viz. (1) control (no nitrogen); (2) farmyard manure (132 kg N/ha); (3) groundnut cake (132 kg N/ha); (4) ammonium sulphate (132 kg N/ha); (5) farmyard manure + ammonium

ORGANIC MANURES

TABLE 81. RESPONSE OF SUGARCANE TO ORGANIC MANURES
AND REGRESSION OF YIELD OVER YEARS (TONNES/HA)

Station: Akluj		State: Maharashtra		Period: 1941-42 to 1949-50		
Treatments	Mean Yield			Linear regression of yield over years		
	No compost	compost	Average	No compost	Compost	Average
Groundnut-cake	115.1	122.5	118.8	—12.40	— 4.96	— 8.68
A/S: G.N.C. (1:1)	100.3	109.8	105.0	—22.25	—10.39	—16.32
A/S: G.N.C. (1:2)	105.8	119.3	112.5	—22.33	— 8.57	—15.45
A/S: G.N.C. (2:1)	83.8	104.6	94.2	—17.54	—10.34	—13.94
Average	101.2	114.0	107.6	—18.63	— 8.56	—13.59
S.E. of difference			S.E. of difference			
(i) between compost means = 2.94			(i) between compost means = 2.80			
(ii) between treatment means = 4.16			(ii) between treatment means = 3.94			

sulphate (each at 66 kg N/ha); (6) ammonium sulphate+groundnut cake (each at 66 kg N/ha); (7) farmyard manure+groundnut cake+ammonium sulphate (each at 44 kg N/ha).

Mean yields are presented in Table 82. There was significant response to the application of nitrogen from all sources. Farmyard manure applied alone gave significantly lower response than the other five nitrogen treatments. The average percentage responses to the dressings of farmyard manure, groundnut cake and ammonium sulphate were 24, 41 and 47 per cent respectively.

On the basis of soil analysis, it was concluded by the author that continuous application of ammonium sulphate did not result in a fall in the pH or in the content of organic carbon or of nitrogen in the soil, to an extent that would make the soil infertile. On the contrary, the yields on these plots were higher than those for any of the other treatments and these differences have been maintained.

Other Crops. In Tamil Nadu, long-term experiments were started in the year 1909 at Agricultural College and Research Institute, Coimbatore in red sandy loam soil with organic manure (FYM) and inorganic fertilizers. From the commencement of the experiment, various crops like Great millet (*cholan*), Finger millet (*ragi*), Common millet (*panivaragu*), Italian millet (*tanai*), cotton, etc. had been raised under irrigated conditions till September, 1937 after which the crops were raised under rainfed conditions. From the results (Table 83) reported by Krishnamoorthy and Ravikumar (1973)

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMLA SOIL

TABLE 82. RESPONSE OF SUGARCANE TO ORGANIC MANURES

Station: Muzaffarnagar		State: Uttar Pradesh	Period: 1949-50 to 1961-62
Treatments	Mean yield tonnes/ha	Mean yield as % of control	
1. Control	45.4	100	
2. F.Y.M. (132 kg N/ha)	56.7	124	
3. G. Cake (132 kg N/ha)	64.0	141	
4. A/S (132 kg N/ha)	66.8	147	
5. A/S + F.Y.M. (132 kg N/ha)	61.9	136	
6. A/S + G. Cake (132 kg N/ha)	64.6	142	
7. A/S + G. Cake+ FYM (132 kg N/ha)	64.1	141	

TABLE 83. RESPONSE OF VARIOUS CROPS TO ORGANIC AND INORGANIC MANURES AT COIMBATORE (TAMIL NADU) DURING 1909 to 1972

Crop	Treatments	Control yield kg/ha	Response kg/ha	Percentage of control	S.E.	C.D.
1. Great millet (<i>Cholam</i>)	Control	601.9	—	—	134.5	372.6
	N		106.9	117.8		
	NP		1038.5	272.6		
	NPK		1041.6	273.1		
	FYM		1323.9	320.3		
2. Finger millet (<i>Ragi</i>)	Control	559.6			78.6	221.5
	N		91.8	116.4		
	NP		1128.7	301.7		
	NPK		1194.1	313.4		
	FYM		932.9	266.7		
3. Italian millet (<i>Tanai</i>)	Control	219.5			47.6	135.8
	N		34.7	115.8		
	NP		275.5	225.5		
	NPK		184.1	183.9		
	FYM		343.7	256.6		
4. Common millet (<i>Panivaragu</i>)	Control	700.6			92.0	260.1
	N		111.9	116.0		
	NP		541.3	177.3		
	NPK		509.2	172.7		
	FYM		526.6	175.2		
5. Cotton (<i>Kapas</i>)	Control	286.8	—		39.4	111.7
	N		26.7	109.3		
	NP		235.4	182.1		
	NPK		210.1	165.8		
	FYM		346.7	220.9		

N @ 25.2 kg/ha; P @ 67.8 kg/ha; K @ 60.5 kg/ha; FYM @ 12.55 tonnes/ha

ORGANIC MANURES

yield data of 5 crops due to some selected manurial treatments have been taken and converted into metric system.

Application of FYM @ 12.55 tonnes/ha every year gave the highest average yield of Great millet (*cholan*), the increase over control being 1,323.9 kg/ha. This yield was 3 times higher than the control but was at par with NPK and NP treatments. Regarding grain yield of Finger millet (*ragi*) average responses of 1,194.1, 1,128.7 and 932.9 kg/ha were obtained with NPK, NP and FYM treatments respectively, the mean yield in control plot being 559.6 kg/ha. In Italian millet (*tanai*), the highest grain yield was obtained with FYM, the response over control yielding 219.5 kg/ha being 343.7, 275.5 and 184.1 kg/ha with FYM, NP and NPK treatments respectively. The order of response in common millet (*panivaragu*) grains were 541.3, 526.9 and 502.9 kg/ha with NP, FYM and NPK treatments respectively, the control yield being 700.6 kg/ha. In cotton crop the response was the highest with FYM (346/7. kg/ha) followed by NP and NPK giving response of 235.4 and 210.1 kg/ha, the yield of control being 286.8 kg/ha. In all these crops, the effects of FYM, NP and NPK fertilizers, were significant over control. However, nitrogen alone gave non-significant increase over control in all crops.

EFFECT OF ORGANIC MANURES IN ROTATION

Pusa (Bihar). A long-term experiment was started in *kharif*, 1932 at the Indian Agricultural Research Institute (Botanical Sub-station), Pusa, Bihar, with a view to determining the effect on soil fertility of organic and inorganic manures, under sub-tropical climatic conditions. The treatments were applied to the following four-year eight-course rotations:

Year	Name of the crop	
	<i>Kharif</i>	<i>Rabi</i>
First year	Maize	Oats
Second year	Maize	Peas
Third year	Maize	Wheat
Fourth year	Maize	Gram

The experimental treatments consisted of all the combinations of two levels of ammonium sulphate, 0 and 44.8 kg N per hectare, two levels of superphosphate, 0 and 89.6 kg P₂O₅ per hectare and two levels of potassium sulphate, 0 and 56.0 kg K₂O per hectare plus two additional treatments, viz. rape-cake at 44.8 kg N per hectare and farmyard manure at the rate of 9 tonnes per hectare (to supply 44.8 kg N per hectare).

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

The inorganic fertilizers alone and in various combinations were applied, half before *kharif* sowing and the other half before *rabi* sowing. The total amount of 9 tonnes of farmyard manure per hectare was applied in the last week of April or first week of May, whereas rape-cake was applied, half before maize sowing and the other half at the last interculture in maize.

The examination of the data showed that farmyard manure treatment and nitrogen in combination with phosphate and potash gave higher response than the remaining treatments. A similar finding was observed with oats and wheat also. On peas and gram, farmyard manure gave the highest response. In general, under all the treatments, there was a deterioration in the rate of response with years. On the whole, plots treated with farmyard manure and rape-cake gave high response for all the crops whereas NP and NPK gave high responses on maize, oats and wheat only.

The results of a few long-term experiments with organic manure and fertilizers discussed above show that although there are some variations in the results obtained, by and large, compost has shown a moderate response and its continued application has been beneficial in reducing deterioration in soil fertility and crop response to fertilizer application.

Shinde and Ghosh (1971) conducted field experiments on manurial requirements of a fixed crop rotation of rice followed by gram from 1955-56 to 1966-67 at Bagwai in Madhya Pradesh in order to study the effect of continuous use of FYM and fertilizers on the yield and fertility status of the medium black soil. Application of FYM at 5.6 tonnes/ha significantly increased the grain yield of rice crop (Table 84) and also resulted in significant increase of organic matter and available phosphorus in the surface layer.

In an experiment with wheat-pearl millet rotation conducted at Hissar during 1971 to 1973 in soil having pH 8.2 (1 : 2), Poonia *et al.* (1974) found that application of FYM at 50 tonnes/ha once in a year before wheat crop gave significant response in wheat and pearl millet crops. Although direct response was low in wheat crop in both years yet response due to residual effect of FYM was comparatively higher on pearl millet being 9.0 and 4.4 q/ha of grains in 1972 and 1973 respectively (Table 85).

Manurial Requirements of a Fixed Crop Rotation

To study the direct, residual and cumulative effect of phosphorus, potassium and farmyard manure on a fixed, single year, two crop rotations with high-yielding varieties of rice, wheat, *jowar*, *bajra* and maize, experiments were conducted all over India in Coordinated Agronomic Research Project. Treatments included all combinations of three levels of phos-

ORGANIC MANURES

TABLE 84. GRAIN YIELD OF RICE CROP (Q/HA) DUE TO FYM (5.6 TONNES/HA) AND PHOSPHORUS LEVELS

Station: Bagwai			State: Madhya Pradesh			Period: 1956 to 1966	
Levels of P_2O_5 kg/ha	FYM $\times$ Phosphate		Mean	Levels of N kg/ha	FYM $\times$ Nitrogen		Mean
	F_0	F_1			F_0	F_1	
0	8.11	15.77	11.94	0	9.50	13.98	11.74
33.6	15.63	16.88	15.75	33.6	13.49	17.25	15.37
67.2	15.75	19.29	17.52	67.2	15.50	20.71	18.10
Mean	12.83	17.31		Mean	12.83	17.31	
C.D. at 5% FYM = 0.64 q/ha; N and P = 0.79 q/ha; FP and FN = 1.12 q/ha							

TABLE 85. YIELD OF WHEAT AND PEARLMILLET CROPS DUE TO FYM AT 50 TONNES/HA (Q/HA)

Station: Hissar		State: Haryana				Period: 1971 to 1973			
FYM	Wheat				Pearl millet				
	1971-72		1972-73		1972		1973		
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	
F ₀	47.8	79.0	34.9	72.7	33.0	105.3	30.1	100.0	
F ₁	49.6	78.0	36.5	83.7	42.0	126.8	34.5	114.1	
Response	1.8	—	1.6	11.0	9.0	21.5	4.4	14.1	
C.D. at 5%	1.0	NS	1.5	5.0	2.5	5.0	0.6	4.6	

phorus (0, 30, 60 kg P_2O_5 /ha) two levels of potassium (0, 30 kg K_2O /ha) and two levels of farmyard manure (0, 15 tonnes/ha) in three phases over a basal dressing of 100 kg N/ha to each crop.

The results obtained with farmyard manure have been briefly given and discussed rotation wise and State wise.

Rice-wheat Rotation

Uttar Pradesh. The data of trials conducted at four stations of Uttar Pradesh from 1969 to 1976-77 have been given in Tables 86 and 87.

1. *Varanasi.* Trials conducted from 1970-71 to 1972-73 showed that application of FYM at 15 tonnes/ha was significantly effective in *rabi*

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

Crop of wheat only: When averaged over 3 years, response of 5 q/ha of total grain yield was obtained when FYM was applied in every season. In 1975, direct, residual and cumulative response of 8.1, 6.8 and 9.0 q/ha were observed in rice crop while response was meagre in wheat in 1975-76. In 1976-77 response to FYM was moderate in rice crop ranging from 2.9 to 4.9 q/ha in different series while in wheat crop responses were fairly high being 4.2, 5.9 and 7.0 q/ha in direct, residual and cumulative series respectively.

2. *Bichpuri*. Trials conducted from 1969-70 to 1972-73 brought out that application of FYM was significantly effective both in rice and wheat crops. When averaged over 4 years, the total grain yield of the two crops increased by 9 q/ha when FYM was applied in every season. This was reduced by one-third when the application of FYM was limited to only one season, *kharif* or *rabi* (Table 86).

3. *Masodha*. Data of 1972-73 to 1974-75 (Table 87) showed that total response of annual grain yield to FYM when applied during *rabi* only was of the order of 12.5 q/ha. The additional response was 1.1 q/ha when FYM was applied in every season. In 1975-76, direct response of 8.2 q/ha was found for wheat crop. In *kharif* rice of 1976, response to FYM was 6.6 and 8.1 q/ha in the residual and cumulative series while in wheat 1976-77, response to FYM ranged from 2.6 to 4.2 q/ha in different series.

4. *Pura Farm*. In rice crop of 1975 and wheat crop of 1976-77, cumulative response of 5.2 and 4.5 q/ha respectively were obtained when FYM was applied in *rabi* only. The trend of results was similar in 1976-77 having cumulative response of 3.6 q/ha in rice and 2.9 q/ha in wheat when FYM was applied in *rabi* only (Table 87).

Madhya Pradesh. Trials were conducted from 1969-70 to 1976-77 at Kathulia Farm, Raipur and Jabalpur and the data has been presented in Table 88.

1. *Kathulia Farm*. FYM was found effective in stepping the yield of rice as well as wheat. The total annual grain yield increased by 8.2, 4.7 and 4.4 q/ha respectively (average of 4 years—1969-70 to 1972-73), by the application of 15 tonnes of FYM in every season, in *kharif* only and in *rabi* only.

2. *Raipur*. Data of 1971-72 to 1973-74 showed that application of 15 tonnes/ha of FYM during *kharif* only was adequate and this increased the annual grain yield by 9.2 q/ha. In the year 1976-77 the response was of the order of 10.7 q/ha in rice and 7.9 q/ha in wheat when FYM was applied in *rabi* only (Table 88).

3. *Jabalpur*. The data of 1972-73 to 1974-75 brought out that total

TABLE 86. DIRECT, RESIDUAL AND CUMULATIVE RESPONSES (KG/HA) TO FYM AT 15 TONNES/HA
ROTATION : RICE-WHEAT

State and Station	Year(s)	Crop	Phase I		Phase II		Phase III				
			Control yield Application in every season	Response C.D. 5%	Control yield Application in <i>kharif</i> only	Response C.D. 5%	Control yield Application in <i>rabi</i> only	Response C.D. 5%			
Uttar Pradesh											
1. Varanas	1970-71 to	Rice	4494	153	190	4696	52	211	4530	63	215
	1972-73	Wheat	4187	352	130	3791	331	142	4026	303	158
	Total over 2 crops		8681	505	232	8487	383	260	8556	366	233
	1975-76	Rice	5502	806	315	4768	681	311	5487	902	244
	"	Wheat	3991	245	220	3766	158	258	4204	241	251
	1976-77	Rice	4669	392	270	4829	488	224	5004	294	249
2. Bichpuri	"	Wheat	2706	419	230	2444	590	186	2740	704	205
	1969-70 to	Rice	2701	265	119	2581	236	155	2696	152	119
	1972-73	Wheat	3816	633	89	3824	406	83	3900	460	87
	Total over 2 crops		6517	898	147	6405	642	154	6596	612	172

TABLE 87. DIRECT, RESIDUAL AND CUMULATIVE RESPONSES (KG/HA) TO FYM AT 15 TONNES/HA
ROTATION : RICE-WHEAT

State and Station	Year(s)	Crop	Phase I		Phase II		Phase III				
			Application in every season		Application in <i>kharif</i> only		Application in <i>rabi</i> only				
			Control yield	Response C.D. 5%	Control yield	Response C.D. 5%	Control yield	Response C.D. 5%			
Uttar Pradesh											
1. Masodha	1972-73 to	Rice	4532	445	97	4456	359	109	4268	352	99
	1974-75	Wheat	2811	918	82	2290	470	104	2708	897	77
	Total over 2 crops		7343	1363	124	6746	829	161	6976	1249	125
	1975-76	Rice	2697	216	171	2635	179	226	2779	185	245
	"	Wheat	2608	820	165	2175	381	268	2234	594	285
	1976-77	Rice	2288	593	179	2700	660	140	2833	810	154
2. Pura Farm	"	Wheat	3329	358	133	2990	260	266	3494	417	142
	1975-76	Rice	3701	240	128	3477	261	149	3728	522	193
	"	Wheat	4654	232	281	4297	192	155	4621	452	122
	1976-77	Rice	3592	317	123	3475	195	121	3877	363	138
	"	Wheat	4821	202	166	4473	220	181	4811	289	140

response of the annual grain yield to FYM when applied in *kharif* only was 17.1 q/ha. An additional, response of 2.6 q/ha was obtained when FYM was applied in every season (Table 88).

West Bengal. The data of trials conducted at Kharagpur from 1972-73 to 1974-75 has been given in Table 89. The total responses of the annual grain yield to FYM was 7.2 q/ha when FYM was applied in *kharif* only and 8.2 q/ha when FYM was applied in every season.

Jammu and Kashmir. At Bagatishero in 1976-77, the response was 4.6 q/ha in rice and 6.6 q/ha in wheat when FYM was applied in *rabi* only (Table 89).

Rice-rice Rotation

Andhra Pradesh. Trials conducted at Tirupati during 1972-73 to 1974-75 showed that application of FYM in every season was beneficial giving annual response of 4.8 q/ha (Table 90).

Karnataka. At Mangalore during 1972-73 to 1974-75 response to FYM was spectacular (Table 90). FYM when applied in *kharif* only increased the annual grain yields by 18.4 q/ha. When applied in every season, the annual grain yield was further increased by about 4.1 q/ha. During 1975-76 response to *kharif* rice was 10.4 q/ha when FYM was applied in *rabi* only and response to *rabi* rice was 11.5 q/ha when FYM was applied in every season, in *kharif* only and in *rabi* only, respectively.

Kerala. Experiments were conducted at Karamana. Application of FYM in every season gave annual response of 8-8.5 q/ha during 1972-73 to 1974-75. In 1975-76 response was 6.7 q/ha in *kharif* rice and 5.1 q/ha in *rabi* rice when FYM was applied in *rabi* only (Table 91).

Orissa. At Bhubaneswar during *kharif* rice of 1976, response to FYM was significant in direct (5.4 q/ha), residual (2.8 q/ha) and cumulative series (4.2 q/ha) while in *rabi* rice response was 3.9, 4.8 and 5.7 q/ha in direct, residual and cumulative series respectively (Table 91).

Tamil Nadu. At Karairuppee, when averaged over 3 years (1971-72 to 1973-74) the annual response to FYM was 4.0, 2.7 and 2.8 q/ha when applied in every season, in *kharif* only and in *rabi* only respectively (Table 92). In 1975-76, response was better when FYM was applied in *rabi* only being 2.9 q/ha in *kharif* rice and 2.5 q/ha in *rabi* rice. Response to FYM was poor in the coastal alluvium soil of Thanjavur.

Maize-wheat Rotation

Punjab. At Ludhiana, FYM immensely benefited maize and wheat crops in all phases and years (Table 93). Taking both crops together, application of FYM in *kharif* season only could be considered as ade-

TABLE 88. DIRECT, RESIDUAL AND CUMULATIVE RESPONSES (KG/HA) TO FYM AT 15 TONNES/HA
ROTATION : RICE-WHEAT

State and Station	Year(s)	Crops	Phase I Application in every season		Phase II Application in <i>kharif</i> only		Phase III Application in <i>rabi</i> only			
			Control yield	Response C.D. 5%	Control yield	Response C.D. 5%	Control yield	Response C.D. 5%		
Madhya Pradesh										
1. Kathulia Farm	1969-70 to	Rice	6190	247	154	6173	309	5798	185	135
	1972-73	Wheat	2819	569	123	2591	157	2671	251	145
	Total over 2	crops	9009	816	200	8764	466	8469	436	208
	1971-72 to	Rice	2351	528	212	2340	518	1769	396	207
2. Raipur	1973-74	Wheat	1476	452	161	951	402	1505	314	202
	Total over 2	crops	3827	980	266	3291	920	3274	710	273
	1976-77	Rice	1824	747	340	1618	664	1313	1075	450
	"	Wheat	2099	632	353	1501	645	2026	786	737
3. Jabalpur	1972-73 to	Rice	3016	946	107	2984	827	2795	687	112
	1974-75	Wheat	1942	1021	86	1719	882	1945	768	92
	Total over 2	crops	4958	1967	139	4703	1709	4740	1455	163

TABLE 89. DIRECT, RESIDUAL AND CUMULATIVE RESPONSES (KG/HA) TO FYM AT 15 TONNES/HA
ROTATION : RICE-WHEAT

State and Station	Year(s)	Crop	Phase I		Phase II		Phase III	
			Application in every year		Application in <i>kharif</i> only		Application in <i>rabi</i> only	
			Control yield	Response C.D. 5%	Control yield	Response C.D. 5%	Control yield	Response C.D. 5%
West Bengal								
Kharagpur	1972-73 to	Rice	3749	61	3711	520	3069	274
	1974-75	Wheat	2261	91	1752	198	2095	234
	Total over 2 crops		6010	117	5463	718	5164	508
Jammu and Kashmir								
Bagtisheroo	1976-77	Rice	4523	348	4275	171	4540	456
	"	Wheat	3363	410	2910	515	3356	660

TABLE 90. DIRECT, RESIDUAL AND CUMULATIVE RESPONSES (KG/HA) TO FYM AT 15 TONNES/HA
ROTATION : RICE-RICE

State and Station	Year(s)	Crops	Phase I		Phase II		Phase III	
			Application in every season		Application in <i>kharif</i> only		Application in <i>rabi</i> only	
			Control yield	Response C.D. 5%	Control yield	Response C.D. 5%	Control yield	Response C.D. 5%
Andhra Pradesh Tirupati	1972-73 to	Rice	5013	268	4998	151	5020	87
	1974-75	Rice	5253	216	5208	127	5329	183
	Total over 2 crops		10266	484	10206	278	10349	270
								140
Karnataka Mangalore	1972-73 to	Rice	3993	1802	3960	1740	3949	518
	1974-75	Rice	3655	453	3569	104	3616	431
	Total over 2 crops		7648	2255	7529	1844	7565	949
	1975-76	Rice	3529	688	3357	280	3526	1044
	"	Rice	3381	1147	2122	62	2068	320
	1976-77	Rice	5194	1608	5187	618	5249	1204
	"	Rice	5735	1448	5688	720	5886	1521
								194

TABLE 91. DIRECT, RESIDUAL AND CUMULATIVE RESPONSES (KG/HA) TO FYM AT 15 TONNES/HA
ROTATION : RICE-RICE

State and Station	Year(s)	Crops	Phase I		Phase II		Phase III		
			Application in every season		Application in <i>kharif</i> only		Application in <i>rabi</i> only		
			Control yield	Response C.D. 5%	Control yield	Response C.D. 5%	Control yield	Response C.D. 5%	
Kerala									
Karamana	1972-73 to	Rice	5490	473	5616	329	5621	10	231
	1974-75	Rice	2870	410	2960	93	2997	117	182
	Total over 2	Crops	8360	883	8576	422	8616	187	338
	1975-76	Rice	5339	484	5840	425	5370	672	280
	"	Rice	2704	210	2748	227	2478	507	302
Orissa									
Bhubaneswar	1976-77	Rice	3216	537	3248	277	3330	417	342
	"	Rice	3282	389	3052	481	3208	572	298

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

quate giving a response of 25.5 q/ha (average of 4 years 1969-70 to 1972-73).

In *kharif* maize, response to FYM was 17.9, 12.4 and 24.1 q/ha in 1975 and 7.8, 10.9 and 9.5 q/ha in 1976 in direct, residual and cumulative series respectively. In wheat, response was 26.0, 25.5 and 25.7 q/ha in 1975-76 and 21.4, 19.5 and 21.9 q/ha in 1976-77 in direct, residual and cumulative series respectively.

Jammu and Kashmir. At Talab Tilloo as per average data for 1971-72 to 1973-74 (Table 93) response to FYM was significant only in the *rabi* crop of wheat, the direct, residual and cumulative effects being 6.2, 4.4 and 5.1 q/ha respectively. However, in maize crop of 1975 and 1976, responses were significant being 7.5, and 4.6 and 4.1 q/ha in 1975 and 11.6, 8.9 and 12.5 q/ha in 1976 in direct, residual and cumulative series respectively. In wheat direct, residual and cumulative responses were 2.1, 7.7 and 3.0 q/ha in 1975-76 and 3.6, 7.3 and 7.9 q/ha in 1976-77 respectively.

Jowar-wheat Rotation

Madhya Pradesh. At Indore, application of FYM during *kharif* only, was found to be adequate, the increase in the annual grain yield being of the order of 7.2 q/ha (Table 94).

Karnataka. At Siruguppa, the annual response of FYM applied in *kharif* only was as high as 26.0 q/ha. Further application of FYM in *rabi* did not increase the annual yield (Table 94).

Bajra-wheat Rotation

Haryana. At Hissar, taking both crops together, response to FYM was nearly the same ranging between 5.4, 5.9 and 6.0 q/ha whether applied in *rabi* or in *kharif* or in every season respectively (Table 95).

Rajasthan. At Jodhpur, FYM applied during *kharif* season only increased the annual grain production by 6.8 q/ha (Table 95).

Gujarat. At Jagudon, there was no response of FYM to *kharif* crop of *bajra*. However, in *rabi* crop of wheat, direct response to FYM was 3.9 q/ha (Table 95).

Rotation-jowar in Kharif-bajra in Rabi

Tamil Nadu. At Bhavanisagar, during 1971-72 to 1973-74 effect of FYM was phenomenal in all phases (Table 96). Its application in every season increased the annual grain yield by 19.8 q/ha and in one season only either in *kharif* or *rabi* by 16.0 and 17.6 q/ha respectively. In the year 1975-76, direct, residual and cumulative responses were 8.8, 3.6 and 4.9 q/ha in *jowar* and 20.3, 10.5 and 18.9 q/ha in *bajra* respectively. In 1976-77,

TABLE 92. DIRECT, RESIDUAL AND CUMULATIVE RESPONSES (KG/HA) TO FYM AT 15 TONNES/HA
ROTATION : RICE-RICE

State and Station	Year(s)	Crops	Phase I		Phase II		Phase III	
			Application in every season		Application in <i>kharif</i> only		Application in <i>rabi</i> only	
			Control	Response	Control	Response	Control	Response
			yield	C.D. 5%	yield	C.D. 5%	yield	C.D. 5%
Tamil Nadu								
1. Karaiyiruppu	1971-72 to	Rice	3246	106	69	115	3189	8
	1973-74	Rice	4143	292	118	159	4358	277
	Total over 2 Crops		7429	398	139	274	7540	285
	1975-76	Rice	5457	257	98	198	5520	295
	"	Rice	3782	243	60	197	3883	248
2. Thanjavur	1972-73 to	Rice	4667	119	78	70	4453	70
	1974-75	Rice	3563	94	71	41	3689	57
	Total over 2 Crops		8330	213	105	111	8142	127

RESPONSE OF CROPS TO ORGANIC MANURES IN NORMAL SOIL

application of FYM in *rabi* only was found more beneficial, the response being 13.7 q/ha in *jowar* and 7.3 q/ha in *bajra* (Table 96).

RESPONSE OF CROPS TO BONE-MEAL

A large number of experiments were conducted at agricultural research stations and in cultivators' fields with bone-meal on rice and wheat. A few experiments were also conducted on other crops. In the majority of these experiments, bone-meal was compared against phosphorus applied in the form of superphosphate. In the agricultural research stations, by and large, there was no response to phosphate applied either in the form of bone-meal or superphosphate. Therefore, the results of these trials are not included. In the cultivators' fields, however, generally there was a good response to phosphate applied in the form of bone-meal. The results of these trials conducted on rice are given in Table 97 and on irrigated wheat in Table 98. The fertilizer was tried at the levels of 22.4 and 44.5 kg P_2O_5 per hectare in these trials. Bone-meal gave moderate to good response on rice crop. On an average, the response was only a little less than that to the application of superphosphate. However, on the acidic soils of Kerala and Tripura, bone-meal gave even a better response than superphosphate.

The response of wheat to application of bone-meal was somewhat lower than in rice. However, the results were available only from Rajasthan.

It appears from the results given above that the bone-meal can be very effective in the acidic areas.

TABLE 93. DIRECT, RESIDUAL AND CUMULATIVE RESPONSES (KG/HA) TO FYM AT 15 TONNES/HA
ROTATION : MAIZE-WHEAT

State and Location	Year(s)	Crops	Application in every season		Application in <i>kharif</i> only		Application in <i>rabi</i> only		
			Control yield	Response C.D. 5%	Control yield	Response C.D. 5%	Control yield	Response C.D. 5%	
Punjab									
Ludhiana	1969-70 to	Maize	3016	1545	154	1358	145	740	149
	1972-73	Wheat	3299	1117	93	1195	113	1195	131
	Total over 2	Crops	6315	2662	220	2553	208	1935	239
	1975-76	Maize	1394	1786	430	1243	231	2414	1495
	"	Wheat	1599	2604	614	2552	633	2571	597
	1976-77	Maize	1896	784	252	1093	339	955	325
	"	Wheat	2370	2140	781	1949	498	2188	671
Jammu and Kashmir									
Talab Tilloo	1971-72 to	Maize	2954	275	293	38	186	188	248
	1973-74	Wheat	3148	624	193	437	235	508	202
	Total over 2	Crops	6102	896	386	475	320	696	362
	1975-76	Maize	3418	751	301	461	292	410	313
	"	Wheat	2451	208	169	774	231	300	354
	1976-77	Maize	1862	1165	232	889	231	1249	346
	"	Wheat	1032	361	145	731	202	787	248

ORGANIC MANURES

TABLE 94. DIRECT, RESIDUAL AND CUMULATIVE RESPONSES (KG/HA) TO FYM AT 15 TONNES/HA
ROTATION : JOWAR-WHEAT

State and Location	Year(s)	Crops	Phase I		Phase II		Phase III		
			Application in every season		Application in <i>kharif</i> only		Application in <i>rabi</i> only		
			Control yield	Response C.D. 5%	Control yield	Response C.D. 5%	Control yield	Response C.D. 5%	
Madhya Pradesh									
Indore	1969-70 to	Jowar	2436	305	2403	186	2083	267	166
	1973-74	Wheat	4314	369	3986	430	4242	290	136
	Total over 2	Crops	6750	674	6389	716	6325	557	153
Karnataka									
Siruguppa	1972-73	Jowar	2151	1957	1685	1821	1829	1560	256
	1974-75	Wheat	2336	601	1783	779	2280	570	129
	Total over 2	Crops	4487	2558	3468	2600	4119	2130	335

ORGANIC MANURES

TABLE 95. DIRECT, RESIDUAL AND CUMULATIVE RESPONSES (KG/HA) TO FYM AT 15 TONNES/HA
ROTATION : *BAJRA*-WHEAT

State and Location	Year(s)	Cross	Phase I		Phase II		Phase III				
			Application in every season Control Response yield	C.D. 5%	Application in <i>kharif</i> season Control Response yield	C.D. 5%	Application in <i>rabi</i> only Control Response yield	C.D. 5%			
Haryana											
Hissar	1970-71 to	<i>Bajra</i>	2856	225	81	2792	288	85	2816	197	81
	1972-73	Wheat	4188	372	154	4093	298	158	4070	340	166
	Total over 2 Crops		7044	597	193	6885	586	176	6886	537	185
Rajasthan											
Jodhpur	1971-72 to	<i>Bajra</i>	1719	319	194	1581	265	191	1743	125	184
	1973-74	Wheat	2442	204	189	2222	415	178	2291	285	141
	Total over 2 Crops		4161	523	290	2803	680	281	4034	410	250
Gujarat											
Jagudan	1971-72 to	<i>Bajra</i>	2052	112	210	2366	114	143	1903	43	202
	1973-74	Wheat	3199	387	322	3408	247	249	3027	240	339
	Total over 2 Crops		6252	499	428	5774	361	291	4930	283	460

TABLE 96. DIRECT, RESIDUAL AND CUMULATIVE RESPONSES (KG/HA) TO FYM AT 15 TONNES/HA
ROTATION : JOWAR IN KHARIF — BAJRA IN RABI

State and Location	Year(s)	Crops	Phase I		Phase II		Phase III				
			Application in every season Control Response yield	C.D. 5%	Application in <i>kharif</i> only Control Response yield	C.D. 5%	Application in <i>rabi</i> only Control Response yield	C.D. 5%			
Tamil Nadu											
Bhavanisagar	1973-74	Jowar	3105	496	365	3114	1069	855	2587	1099	459
	"	Bajra	1904	785	254	1524	526	253	1760	657	187
	Total over 2	Crops	5009	1981	569	4665	1595	546	4347	1756	580
	1975-76	Jowar	1549	796	304	927	358	295	1734	488	301
	"	Bajra	459	2029	372	957	1055	305	434	1890	369
	1976-77	Jowar	2390	512	448	1258	297	370	1564	1366	655
	"	Bajra	1354	329	291	1262	497	319	1375	733	318

ORGANIC MANURES

TABLE 97. COMPARISON OF RESPONSES OF RICE TO BONE-MEAL AND SUPERPHOSPHATE EXPERIMENTS ON CULTIVATORS' FIELDS — T.C.M. TRIALS

State	Centre	No. of experiments	Bone-meal dose in kg/ha (P ₂ O ₅)	Response in kg/ha	Tripple dose in kg/ha (P ₂ O ₅)	Superphosphate response in kg/ha	S.E. of response in kg/ha
Tripura	Agartala	17	22.4 44.8	184 369	22.4 44.8	215 123	123
Assam	Darrang	10	22.4 44.8	166 105	22.4 44.8	197 381	154
Karnataka	Mangalore	34	22.4 44.8	155 172	22.4 44.8	141 203	55
Andhra Pradesh	Samalakota	15	22.4 44.8	240 264	22.4 44.8	289 320	49
Orissa	Kalahandi	83	22.4 44.8	117 98	22.4 44.8	178 326	31
Kerala	Chalakudy	43	22.4 44.8	191 338	22.4 44.8	105 184	49
Madhya Pradesh	Raipur	48	22.4 44.8	86 105	22.4 44.8	105 178	43
Andhra Pradesh	Bodhan	61	22.4 44.8	123 234	22.4 44.8	86 215	49
Average		311	22.4 44.8	148 209	22.4 44.8	166 240	31

TABLE 98. COMPARISON OF RESPONSES OF IRRIGATED WHEAT TO BONE-MEAL AND SUPERPHOSPHATE
EXPERIMENTS ON CULTIVATORS' FIELDS — T.C.M. TRIALS

State	Centre	No. of experiments	Bone-meal		Triple superphosphate		S.E. of response in (kg/ha)				
			Dose in kg/ha (P ₂ O ₅)	Response in kg/ha	Dose in kg/ha (P ₂ O ₅)	Response in kg/ha					
Rajasthan	Raisingnagar	9	22.4	65	22.4	203	191				
			44.8	83	44.8	175					
	Sumerpur	18	22.4	92	22.4	111	200				
			44.8	138	44.8	129					
			Average		27	22.4		83	22.4	157	86
						44.8		111	44.8	157	

IX. RESPONSE OF CROPS TO ORGANIC MATERIALS IN SALT-AFFECTED SOILS

THE applications of various organic manures are very useful practices for reclamation of salt-affected soils. Besides source of plant nutrients, organic manures produce favourable effect on soil physical properties. It counteracts the unfavourable effect of exchangeable sodium. The decomposition of cattle manure and plant residues liberate carbon dioxide and organic acids which help to dissolve any insoluble calcium salts in soil solution and neutralize the alkali present. Decomposition of organic matter improves soil permeability and bacteria present in it increase water stable aggregate.

Organic materials which have been tried for reclamation of salt-affected soils are farmyard manure, compost, green manures, molasses, press-mud, paddy straw, crop residues and different weeds, particularly *Argemone mexicana*. The results on green manures are generally not included in this bulletin since these have been discussed in chapter on 'Green Manures' in the publication of 'Handbook of Manures and Fertilizers' of the I.C.A.R. However, in trials where green manures have been tried with other organic materials, their data has also been incorporated for the sake of comparison. Organic materials have been tried singly or in combination with other organic and inorganic amendments.

The data of past experiments have been converted into metric system for the sake of uniformity.

Response of Crops in Salt-Affected Soils of Punjab and Haryana

In Punjab at Nissang experimental farm, application of 22.2 tonnes/ha of FYM to highly sodic soil doubled the yield of rice (Uppal, 1955) as would be evident from the data in Table 99.

Kanwar and Bhumbla (1961) carried out trials in alkali soils at Kamma (Punjab) from 1956 to 1959-60 and found high response to FYM applied annually at the rate of 38.2 tonnes/ha (Table 100).

Singh (1959) reported that on an alkali soil in Punjab, FYM at 10.2 tonnes/ha plus *dhaincha* green manure at 13.9 tonnes/ha proved superior to green manure with 27.7 tonnes/ha (Table 101).

Dargan *et al.* (1971) initiated some experiments on the use of FYM and gypsum on a sodic soil (Annual Report—CSSRI, Karnal) and found

RESPONSE OF CROPS TO ORGANIC MATERIALS IN SALT-AFFECTED SOILS

TABLE 99. RESPONSE OF RICE TO ORGANIC MATERIALS IN SODIC SOIL AT NISSANG, PUNJAB

Treatments	Control yield (kg/ha)	Response (kg/ha)
1. Control (leaching)	1310	—
2. Press mud @ 222 q/ha	—	520
3. FYM @ 222 q/ha	—	1370
4. <i>Dhaincha</i> @ 222 q/ha	—	1600

TABLE 100. RESPONSE OF CROPS TO FYM @ 38.2 TONNES/HA AND EFFECT ON SOIL pH AT KAMMA, PUNJAB

Crop	Year(s)	Control yield (kg/ha)	Response (kg/ha)	pH (1:2) 0-15 cm	
				Control	FYM
Rice	1956	177	143	9.7	9.4
Rice	1957	795	1180		
Rice	1958	961	1313		
Rice	1959	2467	441		
Senji (grain)	1958-59	283	360		
Senji (fodder)	1958-59	12,357	14,385		
Wheat (grain)	1959-60	427	272		
Wheat (straw)	1959-60	1132	1287	9.4	8.4

TABLE 101. RESPONSE OF RICE CROP TO FYM AND GREEN MANURE IN ALKALI LAND IN PUNJAB

Treatments	Control yield (kg/ha)	Response (kg/ha)
1. Leaching (7.5 cm per week)	251	—
2. Green manure (27.7 tonnes/ha) plus leaching	—	530
3. FYM 10.2 tonnes/ha + Green manure 13.9 tonnes/ha + leaching	—	999

ORGANIC MANURES

TABLE 102. YIELD OF CROPS IN Q/HA DUE TO FYM AND GYPSUM
AT C.S.S.R.I., KARNAL (HARYANA)

Treatments	Berseem fodder	Sugarcane stripped cane	Paddy grain
1. Control	1.5	—	24.5
2. FYM at 25 tonnes/ha	8.3	4.9	35.9
3. FYM at 50 tonnes/ha	17.4	4.7	37.4
4. Gypsum at 25% G.R.	—	143.2	42.3
5. FYM @ 25 tonnes + 25% G.R.	—	213.7	52.9
6. FYM @ 50 tonnes + 25% G.R.	—	357.8	54.6
7. Gypsum at 50% G.R.	94.9	286.5	57.0
8. FYM @ 25 tonnes + 50% G.R.	294.8	374.6	57.6
9. FYM @ 50 tonnes + 50% G.R.	318.9	391.1	68.9
C.D. at 5%	47.7	92.9	8.9
Soil pH at start	10.5	10.6	10.6
Gypsum tonnes/ha @ 25% G.R.	—	9.0	9.0
Gypsum tonnes/ha @ 50% G.R.	11.0	18.0	18.0

TABLE 103. RESIDUAL AND CUMULATIVE EFFECT OF FYM ON RICE
GRAIN AND BERSEEM FODDER AT C.S.S.R.I., KARNAL

Treatments	Rice 1971		Berseem 1971-72	
	Control yield (q/ha)	Response (q/ha)	Control yield (q/ha)	Response (q/ha)
1. FYM @ 0 tonnes/ha	70.5	—	878	—
2. FYM @ 25 tonnes/ha	—	8.0	—	39
3. FYM @ 50 tonnes/ha	—	13.0	—	136
C.D. at 5%	—	5.7	—	83.0

TABLE 104. DIRECT EFFECT OF FYM ON MAIZE GRAIN AT C.S.S.R.I., KARNAL

Treatments	Control yield q/ha	Response q/ha
1. FYM @ 0 tonnes/ha	23.4	—
2. FYM @ 25 tonnes/ha	—	5.8
3. FYM @ 50 tonnes/ha	—	5.1
C.D. at 5%	3.5	—

RESPONSE OF CROPS TO ORGANIC MATERIALS IN SALT-AFFECTED SOILS

TABLE 105. HEIGHT INCREMENT (CM) OF DIFFERENT FOREST SPECIES ON SALINE SODIC SOIL AT KARNAL UNDER DIFFERENT TREATMENTS

Soil treatments	<i>Acacia arabica</i>	<i>Albizia lebbeck</i>	<i>Eucalyptus hybrid</i>	<i>Prosopis juliflora</i>	<i>Terminalia arjuna</i>
Control (Sodic soil)	40	15	33	46	25
F.Y.M.	76	46	62	81	68
Gypsum	88	62	91	92	85
Gypsum + F.Y.M.	102	71	120	102	95
Normal soil	107	87	119	100	98

TABLE 106. CHANGES IN HEIGHT OF *Eucalyptus Hybrid* UNDER DIFFERENT TREATMENTS OF SODIC SOIL

Soil treatments	Height in metres			
	1971	1972	1973	1974
Control (Sodic soil)	0.90	—	—	—
F.Y.M.	0.90	2.20	3.50	4.90
Gypsum	0.90	2.50	4.00	5.10
Gypsum + F.Y.M.	0.90	2.70	4.40	6.20
Normal soil	0.90	3.10	4.40	6.10

that in the first crop of berseem, sugarcane and rice grown in separate fields having pH 10.5 and above, there was high order interaction of combined application of FYM and gypsum (Table 102).

In the experiment started with berseem as the first crop, rice crop variety 'IR8-68' was taken in *kharif* 1971 and berseem in *rabi* 1971-72 without adding any more FYM or gypsum. Results reported by Dargan *et al.* (1976) showed that the effect of F.Y.M. added to the first crop of berseem was significant on two succeeding crops of rice and berseem (Table 103). In the same fixed layout, there was no further response of FYM in rice of 1972 and berseem of 1972-73. In *kharif* 1973, FYM at 0, 25 and 50 tonnes/ha was added again as per original treatments and maize variety 'Vijay' was taken. Dargan *et al.* (1976) reported that the direct effect of FYM @ 25 tonnes/ha was highly significant on maize grain yield (Table 104).

In field experiments at C.S.S.R.I., Karnal initiated in 1970 on sodic soil with pH above 10.0, Yadav *et al.* (1972) found that the growth of *Eucalyptus hybrid* after treating the soil with gypsum @ 50 per cent G.R.

ORGANIC MANURES

and FYM in planting pit was almost as good as in the original alkali soil replaced with good soil. Yadav *et al.* (1975) made similar observations on height increment of different species during the period of September 1974 to September 1975 in the same experiment (Table 105).

Yadav and Sharma (1976) in a separate field experiment at C.S.S.R.I., Karnal observed that the height growth of *Eucalyptus hybrid* during 1971 to 1974 in combined application of gypsum and FYM treatment was as good as in the normal soil and was much superior to that obtained in treatments of gypsum or FYM applied alone (Table 106).

TABLE 107. RESPONSE OF WHEAT TO ORGANIC MANURES

Ballop area (Kota)—Rajasthan—1968-69				
Treatments	Control yield q/ha		Response q/ha	
	After <i>jowar</i>	After Fallow	After <i>jowar</i>	After Fallow
1. Control	19.85	16.00	—	—
2. F.Y.M.			1.78	2.91
3. Gypsum			5.44	4.46
4. <i>Dhaincha</i>			1.72	2.32
5. F.Y.M. + <i>Dhaincha</i>			6.53	5.84
6. F.Y.M. + Gypsum			6.28	5.62
7. Gypsum + <i>Dhaincha</i>			4.08	3.70
8. F.Y.M. + Gypsum + <i>Dhaincha</i>			6.54	6.98
C.D. at 5%			1.75	2.20

Mendiratta *et al.* (1972) reported that in *jowar*-wheat and fallow-wheat rotation, gypsum in combination with either FYM and/or *dhaincha*, appeared to be the best treatment in increasing the yield of wheat grain in Ballop area (Kota) of Chambal Command affected with salinity and alkalinity (Table 107).

X. RECOMMENDATIONS

1. It is recognised that bulky organic manures, in particular, play their role in increasing crop yields through (a) supply of plant nutrients; and (b) improvement in several factors of soil fertility like the physical, chemical and biological properties of soils. Variable and often non-significant responses that are obtained through the use of these manures are now understood to be owing mainly to the low availability of nitrogen in them and consequently their inability to make good the primary deficiency of nitrogen in the dose applied. It is, therefore, recommended that effective use of such manures should be made by (a) use in adequate quantity, if available, on the basis of their content of plant utilisable nitrogen, (b) use in combination with fertilizer nitrogen in quantity to provide adequate nitrogen for the requirements of crops, and (c) use after enrichment with nitrogen as described earlier. Since the quantity of manure available with farmers is much short of their requirements, the latter two alternatives provide a solution that would invariably give an assured response.

2. It must be realized that high crop yields induced by adequate fertilization with NPK salts are bound to project sooner or later the need for adjustment of other elements, from time to time to maintain the productive capacity of soils. It is in this role of supplying various secondary and trace elements that complex organic manures of this type can be relied upon to make good known and unknown deficiencies and rectify any adverse residual effects of fertilizers, particularly in their long-term use.

3. The urine component of cattle and buffalo excreta contains 50 to 70 per cent of total nitrogen and 90 to 95 per cent of the total potash excretion. The separate collection and utilization of urine absorbed and dehydrated in waste materials offers great scope for exploiting a potential source of highly effective manure available with every farmer. As an alternative to the recommended practice of adding urine-soaked litters to the manure heap, this approach would enable the limitation of fermented manures to be overcome and a high efficiency obtained from the liquid and solid excreta.

4. The saving of about 29 per cent of dung that is presently being burnt away as fuel in villages and its use as manure is a consideration of great practical importance in the context of the new strategy for increasing crop production. There is, no doubt, that in the present economy, the practice of burning cattle-dung as fuel to a limited extent is inescapable in rural

ORGANIC MANURES

areas and will continue at least for some more time. The question has, however, received attention and various solutions have been suggested, viz. (a) the programme of installing and popularizing gas plants in the rural areas should be intensified; (b) since the use of soft coke in rural areas is not going to be cheaper in view of the tremendous cost of transport and other factors involved, the popularization of soft coke in urban and semi-urban areas may release wood to some extent for use as fuel in rural areas, thereby releasing cattle-dung for manurial purposes ; (c) to augment the wood supply for fuel purposes in rural areas, stress must be laid on farm-forestry programme; and (d) the quality of manure should be improved by adoption of scientific methods of composting and minimizing losses of plant nutrients. The programme of setting up biogas plants involves high cost of installation with KVIC plants whereas the Janata biogas plant is cheaper by 40 to 50 per cent. Hence, the biogas recovery in rural farm-sheds through the Janata biogas plant programme should be intensified.

5. The technology on the method of composting available in the country is sound. However, the methods followed by the farmers are substandard. Composting of surplus and available farm wastes such as straw, leaf fall, weeds, water hyacinth and animal dung should be practised by improved methods of composting available in the country for augmenting/supplementing the nutrients supply and humus substances for higher crop yields.

6. Preparation of rock phosphate digested compost is recommended. Low-grade rock phosphate @ 10 kg/tonne of organic material is recommended to apply while preparing the compost by pit or heap method. It has been found that rock phosphate application hastens the process of composting and improves the quality of compost.

7. The use of mesophilic cellulolytic (*Aspergillus* spp., *Penicillium* spp., *Trichurus spiralis*) inoculants is recommended for rapid composting of dry and high C/N ratio (Table 40) farm wastes such as straw of different types, leaf fall, etc. It has been observed that by inoculating the compost heaps by an efficient and suitable culture, the composting period can be reduced with a net gain in nitrogen.

8. Mechanical composting has made good progress in the country and semi-mechanised plants are more suitable to Indian conditions because of the advantage of low cost. The success of mechanical composting plants should not be judged purely on economic considerations because public health and checking of environmental pollution by systematic disposal of solid and liquid wastes is an important factor.

9. Concentrated organic manures like oil-cakes, blood, meat, fish and bone-meals are sold in our country at abnormal premium as compared

RECOMMENDATIONS

with chemical fertilizers of equal plant nutrient capacity. This does not appear to be justified on the basis of responses obtained with them which are at best equal to or slightly better than fertilizers. Considering also that the quantity of organic matter that gets applied by the use of such organic manures is rather small and of little practical consequence, the prices paid for organic nitrogen from such sources are not commensurate with the returns obtained in crop yields, unless their prices are reduced. It should be realized that organic forms of nitrogen are first converted into mineral forms of ammonia and nitrate, before this element is assimilated by plants so that there is no particular superiority in effect that can be expected from this. Actually, organic manures do not nitrify completely and a part of their nitrogen always remains untransformed and, therefore, unutilizable. Low-grade oil-cakes can be ammoniated or enriched with fertilizer for fuller and more effective use.

10. Sewage water besides irrigation, adds plant nutrients to the soil and increases crop yields from 30 per cent to 50 per cent in food crops and 100 per cent in fodder crops as compared with ordinary irrigation water. The sewage water must, therefore, be fully exploited for increased crop production.

11. Organic materials rich in cellulose and lignin such as crop wastes, straw @ 5 to 10 tonnes/ha can be recycled in the first instance as surface mulch and subsequently after one season partially degraded straw should be incorporated in the soil. This is a cheap method of utilisation of surplus crop residues instead of burning it. The results have shown that organic mulch is helpful in increasing the yield of crops significantly as well as the second crop when the left-over organic matter is ploughed in the soil.

12. Another promising method for direct disposal of crop wastes such as paddy or wheat straw can be followed by incorporating the organic material @ 5 tonnes/ha and allowed it to decompose for a week followed by growing of a legume crop to advantage. The results have shown that the yield of legume crops can be increased by ploughing in straw.

13. It is recommended that adequate quantity of organic manure should be used in alkali soils in combination with gypsum as combined application interacts significantly in increasing the crop yields and also produces favourable effect on soil physical properties.

14. Further experimental evidence is needed on the comparative response and economics of various organic manures in relation to fertilizers and the effect of their combined application. Experiments are also necessary to study the effect of smaller applications of bulky organic manures, fortified with nitrogen and non-symbiotic nitrogen fixing bacteria (*Azoto-*

ORGANIC MANURES

bacter) and phosphorus solubilising bacteria (*Pseudomonas striata*, *Bacillus polymyxa*).

Experience of users of organic manures has indicated that the quality of crops, particularly fruits and vegetables is superior to the quality obtained with chemical fertilizers. It would be useful to obtain some conclusive experimental evidence on this aspect relating to determinable quality factors like nutritive value, storage properties, colour, mineral and organic composition, etc.

It is often argued that even if dung is not at all used as fuel and all available organic wastes with manurial value are carefully conserved and returned to the land, the supplies of plant nutrients cannot be adequate to improve and maintain optimum soil fertility. This may be true but in view of the various advantages of organic manures, it is not at all convincing that the improvement that can be brought about by the development of local manurial resources is not worth the trouble. The manurial policy of the farmers should, therefore, be to take every possible step to ensure the return to the land of all organic waste materials and supplementing such materials with chemical fertilizers adequately.

XI. AVERAGE CHEMICAL COMPOSITION OF DIFFERENT MANURES

Manure	Nitrogen %	P ₂ O ₅ %	K ₂ O %
Dried blood	10-12	1-2.6	0.8
Bone-meal (Raw)	3.0	20.0	—
Bone-meal (Steamed)	—	22.0	—
Meat-meal	10.5	2.5	0.5
Bone-ash	—	15.5-16.0	—
Fish-meal	4-10	3-9	0.3-1.5
Bird-guano	7-8	11-14	2-3
Tankage	11-12.5	1-2	—
Activated sludge	5-6	3-3.5	0.5-0.7
Settled sludge	1.5-4.5	0.7-4.0	0.3-0.6
Cotton mill flue-dust	1.5-2.0	0.5-0.6	0.6-0.8
Night-soil	1.2-1.5	0.8	0.5
Human urine	1.0-1.2	0.1-0.2	0.2-0.3
Cattle-dung	0.3-0.4	0.1-0.15	0.15-0.20
Cattle-urine	0.8	0.01-0.02	0.5-0.7
Town compost	1.5-2.0	1	1.5
Farmyard manure or farm compost	0.5-0.6	0.15-0.2	0.5-0.6
Sewage	15-30 ppm	4-6 ppm	10-20 ppm
Water hyacinth compost	2	1	2-3
Tank-silt	0.3	0.3	0.3
Poultry-litter	3.03	2.6	1.4
Seaweed	1-2	1-2	2-7
Leather-waste	7.0	0.1	0.2
Hair and wool-waste	12.3	0.1	0.3
Press-mud	1-1.5	4-5	2-7
Bagasse	0.25	0.12	—
Molasses:			
i) Sulphitation	0.24	0.078	2.84
ii) Carbonation	0.17	0.03	2.8
Tea leaves (used)	2.8-3.6	0.3-0.4	1-1.9
Castor-cake	5.5-5.8	1.8	1.0
Coconut-cake	3.0-3.2	1.8	1.7
Cotton-seed cake:			
i) under-corticated	3.9-4.0	1.8	1.6
ii) decorticated	6.5	2.8	2.1
Dhupaka-cake	1.1	0.2	—
Groundnut-cake			
i) decorticated	7.8	1.5-1.9	1.4
ii) under-corticated	4.5	1.7	1.5
Jambo-cake	4.9-5.0	1.6	1.8
Karanj-cake	3.9-4.0	0.9-1.0	1.3
Linseed-cake	5.5	1.4	1.2
Mahua-cake	2.5-2.6	0.8	1.8
Mustard-cake	4.5	1.5	—
Neem-cake	5.2	1.0	1.4
Niger-cake	4.8	1.8	1.3
Pungam-cake	2.5	1.0	—
Rape-seed-cake	5.1	1.8	1

ORGANIC MANURES

Manure	Nitrogen %	P ₂ O ₅ %	K ₂ O %
Safflower-cake			
i) under-corticated	4.8	1.4	1.2
ii) decorticated	7.8	2.2	2.0
Sesame-cake	6.2	2.0	1.2
Undi-cake	3.6	1.5	2.0

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